RESPONSE GUIDED ERRORLESS LEARNING WITH NORMAL ELDERLY

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This study investigates the use of response guidance for errorless learning of a perceptual motor task in normal elderly. It provides normative data for a study with stroke patients using this technique for cognitive rehabilitation. While errorless learning has been shown to be more effective on most tasks than trial and error learning for people with memory impairments, its use with normal individuals has received limited attention. The questions of interest were whether errorless training of the perceptual motor task was more effective for improving and retaining accuracy; and whether both accuracy and response speed were more resistant to the effects of increased cognitive demands.

A sample of 43 normal elderly in the United Kingdom, ranging in age from 60 to 77, completed an assessment of intelligence, memory, and attention. They then received training, over two sessions one week apart, to mark the midpoint of Judd Arrows presented on a computer screen using a cross cursor moved by an active force feedback joystick (AFF). During training the errorless group received AFF guidance to the correct midpoint, while the errorful group received none, and both received auditory and visual knowledge of results. There was no AFF during baseline or post test measures. Training was to criterion in each session with a discontinue rule if accuracy did not improve. At the end of session two both groups were given a cognitively challenging task concurrent with the arrow bisection. Results revealed that both groups improved their accuracy through training with the errorless group being significantly more accurate and tending to be faster in the final post tests of both sessions. The errorless group was significantly faster than the errorful group under the cognitive challenge, without sacrificing accuracy. These results suggest not only that AFF is an effective means of implementing errorless perceptual motor learning, but elderly individuals trained in this manner do not sacrifice accuracy for speed. Implications of these results are discussed.

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Introduction

This study investigates the use of response guidance to implement errorless learning of a perceptual motor task in normal elderly comparing their performance on the dimensions of accuracy, retention, and resistance to cognitive demands with a control group who receive trial and error training. This investigation is designed to provide normative data for a study with stroke patients using response guided errorless learning for the rehabilitation of cognitive deficits.

A. Two studies laying the foundation for the present investigation will be reviewed.

B. Thereafter, literature relevant to the current study will be surveyed. This review will address:

   1. normal performance on line bisection and on the visual illusion used in this investigation;
   2. the foundations of errorless learning and prior research with this technique;
   3. the use of active force feedback to implement errorless learning;
   4. the role of implicit and explicit memory in errorless learning;
   5. the implications of normal cognitive aging for the present study.

During relearning of tasks following brain damage it has been shown that neurological patients tend to remember and perseverate incorrect responses and are unable to benefit from correct feedback responses during their actions and movements. This impedes the learning process. In the case of amnesia as a result of brain injury, errorless learning has been shown to be superior to trial and error learning. While errorless learning is a proven method of teaching new information to individuals with memory problems, its potential effectiveness with other types of cognitive and perceptual motor deficits, as well as with unimpaired individuals, is not certain. The reason to question this is that errors are generally believed to be essential for learning to occur. In an effort to establish normative data for a project aimed at cognitive rehabilitation using response guided errorless learning following stroke, this study induces a “cognitive deficit” with normal elderly participants using the Judd Arrow (Judd, 1899) visual illusion.

A. The Foundation Studies for the Present Investigation

Marking the midpoint of a horizontal line (line bisection) is sensitive to unilateral spatial neglect (USN), an attentional disorder commonly associated with damage to right parietal cortex (DeRenzi, 1982) frequently found in stroke patients. The neglect usually results in bias towards the end of the line in the unaffected visual field, ipsilateral to the lesion. In examining the efficacy of errorless learning in the remediation of hemispatial neglect in stroke patients, normal models of bias in line midpoint judgments have been explored (Kashmere & Kirk, 1997; Manning, Halligan, & Marshall, J.C., 1990; Milner, Brechmann, & Pagliarini, 1992; Schwartz, Adair, Na, Williamson, & Heilman, 1997; Werth & Poppell, 1988). In normals, line bisection can be biased by flanking marks placed at each end of the line. In the Judd figure, an arrow head and tail at either end of the line cause the midpoint to be placed too near the tail. The effect appears to be related to clues to the size of the object in the three dimensional world (Gillam, 1986). Since the tail projects beyond the end of the straight line, it might be possible that the midpoint bias is a result of the participant marking the center of the overall figure, due to attentional focussing (Shuren, Jacobs, & Heilman, 1997) instead of just the straight line. To assess whether this bisection bias in normals could be a model for USN, a preliminary study was carried out to determine if the two ends of the Judd figure contributed equally to the illusion or whether, for example, attention was drawn towards the tail with resulting neglect of the other end of the line (Connor & Wing, 1999).

Participants were asked to mark midpoints of horizontal straight lines 12.5 cm long presented one at a time in the middle of a computer display. The trials included plain lines and lines embedded in the Judd figure, pointing left (L) or right (R). Trials also included the Judd figure with enlarged arrow head or tail, pointing either L or R, based on Chieffi’s (1996) study modeled after Baldwin’s (as cited in Chieffi) finding that the localization of the subjective midpoint of a line is influenced by the relative size of stimuli presented at either end. Connor and Wing (1999) were interested to see whether the bias would be selectively affected by the length of the tail lines. Subjects used cursor keys on a computer keyboard to mark midpoints by advancing a vertical line which moved in from L or R sides of the display on alternate trials. If the Judd figure provided a normal model for spatial neglect, then advancing the line over the tail would increase the bias toward that end due to center of mass effect (Shuren et al., 1997). Each stimulus type occurred twice. Nine subjects were tested. The results showed the Judd figure produced a reliable bias towards the tail in marking the midpoint. Under conditions in which head and tail segments of the Judd figure were unequal in size, the bias in marking the midpoint was the same whether the head or tail was enlarged. The illusion induced by either end of the Judd arrow did not interact with the direction in which the marker line was advanced, though there was a slight tendency toward moving in over the arrow head producing a larger bias toward the tail. While this study found a reliable bias in marking the midpoint of a horizontal line, the results demonstrated that this could not be attributed to the projection of the arrow tail beyond the end of the target line but represented equal contributions from head and tail arrows, such that the visual pattern at either end influenced midpoint judgment. This symmetry of effect at either end was consistent with Post, Welch, and Caufield (1998) who showed equal bias at both ends of the line when participants attempted to subdivide the Judd figure into 8 equal segments. The authors concluded the bias induced by the Judd figure was not due to the one end alone but to both ends, however, the visual error produced by the Judd figure could be used for training purposes since it reliably induces a perceptual distortion (Connor & Wing, 1999).

Subsequently, the Judd figure was used in a pilot study to investigate errorless learning in the training of perceptual motor relations (Connor, Wing, & Bracewell, 2000). Ten normal participants, age range 20 to 69 years, five female and five male, bisected a series of individually presented horizontal Judd Arrows (7.5 x 3 cm), displayed on a computer screen, using a cross cursor moved by an active force feedback (AFF) joystick. Each trial consisted of a single Judd Arrow presented in any location on the screen. There were equal numbers of R and L pointing arrows randomly presented during each block of trials. Baseline and post training blocks consisted of ten trials each without force feedback. Training was one block of 20 trials that was either errorless or errorful. During errorless training the joystick defined a force field “valley” within which the cursor could only be moved to the target midpoint. Initial baseline midpoint accuracy, followed by training, then post training accuracy was recorded. In the errorless training the force feedback was turned *on* and in the errorful training force feedback was turned *off*. Both conditions included onscreen semantic knowledge of results (KR), “YOU HIT THE MIDDLE” or “MISSED.” Measurements were expressed in screen pixel distance from the actual midpoint (1 pixel = 0.4 mm). Each participant received both types of training, on two separate days one week apart, with initial training type counterbalanced between subjects. There was no KR during the baseline or post training blocks of trials.

No practice effect was evident as there was no significant difference between mean baseline midpoint accuracy for the two training sessions. This was not surprising given the limited number of training trials. A three way repeated measures ANOVA comparing type of training, pre versus post training accuracy, and arrow direction (R or L) showed main effects for pre versus post training and arrow direction, $F\ (1,7) = 8.27$, $p < .05$, without interaction effects. From this study it was evident that normal participants were able to learn to correct perceptual judgement errors with training. The study also showed that it was possible to safely and effectively deliver errorless learning with response guidance using an AFF joystick. While the response guided errorless learning was shown to be as effective as trial and error learning on this perceptual motor task there was, however, no significant difference in performance between the two groups (Connor et al., 2000). Small sample size may have limited the likelihood of detecting a difference in training type between errorless and errorful learning.

These experiments form the background for the current study in which the Judd figure displayed on a computer screen is used with an AFF joystick to address the following questions:

(1) Is errorless training more effective than trial and error (errorful) training for improving accuracy on a perceptual motor task?

(2) Is there greater retention of accuracy on the perceptual motor task when training is errorless than when it is errorful?

(3) Is accuracy more resistant to the effects of increased cognitive demands when training is errorless than when it is errorful?

(4) Is response speed more resistant to the effects of increased cognitive demands when training is errorless than when it is errorful?

B. Literature Review

1. Normal Performance on Line Bisection and the Judd Arrow Illusion

The task of asking neurological patients to bisect a line as a test for unilateral neglect has been used for years. Typically the score is the length by which the patient's estimate of the center deviates from the true center. However, there has been increasing interest in recent years in how normal subjects perform on line bisection tasks, to determine if specific biases are present in the absence of brain damage. Lezak (1995) reports studies with normal subjects that show a leftward bias on horizontal lines, typically deviating one to two millimeters (mm), depending on line length (Weber's Law that a stimulus must be increased by a constant fraction of its value to be just noticeably different, as cited in Manning et al., 1990). Manning and colleagues found in normal subjects a substantial between-subjects variation in both the magnitude and direction of the linear regression of transection displacement as well as an uncorrelated magnitude of linear regression of standard deviation on line length. Thus, positive linear relationships between stimulus length and transection displacement, as well as standard deviation of transection displacements are not abnormal, however, the magnitude of these effects is much smaller than is obtained with patients with neglect.

Riddoch and Humphreys (1983) found that cueing patients with neglect to the left most end point of horizontal lines improved the accuracy of their midpoint bisections. This effect has also been demonstrated in normal subjects who make bisection errors toward whichever end of a line is explicitly cued (Milner et al., 1992). Milner and colleagues found that the left-ward bias in line-bisection in normal subjects is partly the result of perceptual bias since normal subjects see lines bisected centrally as slightly bisected to the right and lines bisected slightly left as being centrally bisected. From this they conclude that the right hemisphere plays a dual role to both enhance the perceptual salience of spatial stimuli in the left hemispace and to activate leftward orienting response tendencies. This dual role is particularly relevant in USN as this condition fractionates into sensory neglect (visual, tactile and/or auditory) and sensory motor neglect for responses to stimuli in left hemispace.

In a study to determine if the horizontal spatial bias found in normal subjects was dissociable into sensory-attentional and motor-intentional subgroups Schwartz and colleagues (1997) found that the sensory attentional system strongly influenced performance on a line bisection task while a cancellation task was influenced by both the sensory-attentional and motor-intentional systems. Sensory-attentional represents the sensory perception of the spatial location of stimuli while motor-intentional refers to the motor response to stimuli. From this study the authors conclude both systems may be yoked to each other and to a representation of contralateral hemispace, such that it is the degree or direction of interaction that determines the multi-dimensional spatial bias found in normal subjects.

Visual illusions have been studied for over 100 years during which many different explanations have been proposed to explain their effects. Consensus has been reached on three fundamental points. One, the illusions are mainly perceptual and not conceptual; knowing a particular effect is illusory does not diminish the strength of the illusion though repeated exposure does reduce its effect. Two, most illusory effects do not originate in the retina but must rather originate beyond the lateral geniculate nucleus (LGN) of the brain where the inputs of the two eyes come together since the effects remain at almost full strength when the component creating the distortion (inducing component) and the component being distorted (test component) are presented one to each eye. In the Judd Arrow figure the arrow head and tail are the inducing components and the shaft of the arrow is the test component. Third, contrary to Judd's (1899) movement hypothesis which is based on the sensation of movement resulting in an active tension of the muscles of the eye created by the illusion, these visual illusions do not result from the movements of the eye. Experiments have shown that the full magnitude of the illusion emerges both when the image is exposed too briefly for the eye to scan it or when the image of the figure is artificially stabilized on the retina while the eye moves back and forth (Gillam, 1986). Festinger et al. (as cited in Gillam) found when individuals attempt to fixate on the ends of a Muller-Lyer figure, they actually fixate within the arrowheads which has the effect of lengthening the line with the inward-pointing arrowheads and shortening the line with the outward-pointing ones. This effect, applied to the Judd figure, causes the inward pointing end of the figure to be lengthened and the outward pointing end to be shortened.

Before examining the role of selective visual attention relative to visual illusions in normal individuals, it is useful first to review the broader attentional system. Posner and Peterson (1990), in studying the intact human brain, have found three inter-related mechanisms, operating semi-autonomously, that form the basis of attention: orienting, selection, and alerting/sustained attention. Orienting, also referred to as the posterior attention system, is believed to be based largely in the posterior parietal lobe, the superior colliculus, and the lateral pulvinar of the posteriorolateral thalamus, and involves the initial sensory awareness of the stimulus. Selection involves the focal or conscious attention system, which is closely related, both functionally and anatomically, to the posterior attention system. This system, related to target selection and recognition, has its anatomical basis in the anterior cingulate and supplementary motor areas. Alerting or sustained attention is the system involved in sustaining a preparation to respond in the absence of salient or novel external stimuli, which engage attention automatically via orienting. The right hemisphere appears to be specialized for alerting or sustained attention. Further, norepinephrine (NE) may be the mechanism for sustained attention and there is evidence for a right hemisphere bias in the NE system. The sustained attention system has been shown to have a strong effect on the posterior attention system of the right hemisphere, an area strongly implicated in neglect, acting to increase the rate at which high priority information can be oriented to and selected for further processing. As such, the posterior attention system can be influenced both by its own mechanisms, as well as by the modulatory effect of a right-hemisphere dominant, NE based, alerting/sustained attention system.

Allport (1989) reviews the neurophysiological and neuropsychological evidence for multiple parallel channels involved in attentional functions and describes the spatial direction of attention as a group of subsystems of the broader attentional system forming a complex distributed network of both cortical and subcortical components. The subsystems relevant to spatial attention include the posterior parietal cortex, posterior cingulate cortex, frontal eyefields, various thalamic nuclei, basal ganglia, superior colliculus, and midbrain reticular formation. As such, spatial attention is a distributed process in which many functionally differentiated structures participate, rather than there being a single center for this function. It is not surprising that injury to individual components of the network result in highly specific patterns of attentional impairment, selectively affecting the engagement, maintenance, disengagement, and shifting of spatial attention.

Theories of selective attention generally assume that the primary role of selecting some stimuli while rejecting others allows the brain to process the selected stimuli more efficiently than would be possible if the brain tried to process all the stimuli at once. Luck, Girelli, McDermott, and Ford (1997) have proposed the “ambiguity resolution theory," similar to feature integration theory, to explain this phenomena as the primary role of selective visual attention. However, unlike feature integration theory which holds that the separately coded features of a given stimulus cannot be localized or combined unless attention is focused on that object, this theory proposes that the primary computational role of selective attention in the visual system is to resolve ambiguities in neural coding that occur when multiple stimuli or stimulus features are processed simultaneously.

The role of selective visual attention in responding to illusory figures has been investigated extensively. Studies of the neural mechanisms of selective visual attention reveal that objects in the visual field compete for limited processing capacity and control of behavior at several points between input and response. The competition is influenced by bottom-up neural mechanisms that separate features from their background in space and time, and by top-down processes that select objects relevant to current behavior. These biases can be influenced by various stimulus attributes including spatial location, simple object features, and complex conjunctions of features. Within the ventral stream, specialized for object recognition, top-down inputs resolve competition primarily between objects located within the same receptive field, which likely work in a similar way for both object and spatial selection. Since many spatially mapped structures contribute to competition, unilateral lesions will lead to neglect and extinction syndromes that do not implicate a specific role in attentional control. The templates involved in the top-down selection process for both objects and locations are derived from neural circuits mediating working memory, most likely in prefrontal cortex (Desimone & Duncan, 1995).

In a study examining the distribution of attention in space in normal subjects Reuter-Lorenz, Kinsbourne, and Moscovitch (1990) showed that attention in space, when activated by lateralized sensory input, is biased in the direction contralateral to the activated hemisphere. This bias, which is of equivalent strength in each hemisphere, is not dependent on either task relevance or the hemispatial position of the stimulus producing the attentional imbalance. Each hemisphere generates a contralateral attentional bias. Their study found in normal individuals the rightward bias of the left hemisphere is the stronger of the two in spatial orienting and selectivity, in contrast to the view that with USN, the dominance of the right hemisphere involves its ability to attend to both sides of space while the left hemisphere attends to the right only. This finding contrasts with Milner et al.'s (1992) suggestion that the right hemisphere should be dominant as a result of its dual role in enhancing the salience of stimuli in the left visual field while also activating left orienting responses.

The Judd Arrow visual illusion has been used to examine the phenomenon of unilateral neglect of visual space in both normal individuals and those with right hemisphere brain damage with and without USN. Fleming and Behrmann (1998) developed an "analog" of neglect in normal participants using bisections of the Judd visual illusion, with arrow direction pointing left, right or both, and fin angle of 14, 45, and 76 degrees. Participants made bisection errors that were significantly biased in a direction opposite to the direction in which the arrows or fins were pointing, with the errors decreasing as the fin angle increased. These investigators concluded the geometric properties of the Judd figure have a sufficiently strong influence on the representation of space that it may be used to induce a distorted perception of space analogous to that found in patients with USN. In a related study Post and colleagues (1998) found, when normal participants were asked to divide the shaft of Judd figures into eight equal lengths, there was a continuous change from contraction of the estimated line length nearest the tails-in vertex (arrow head) to expansion nearest the tails-out vertex (arrow tail). As previously discussed, Connor and Wing (1999) found the bias induced by the Judd figure was not due to one end of the figure but to both ends which is unlike the inattention to one end of a stimulus figure found in USN. Nonetheless, the visual error produced by the Judd figure could be used for training purposes since it reliably induces a misperception of the midpoint of the arrow shaft.

In using this figure with patients with USN Mattingley, Bradshaw, and Bradshaw (1995) and Ro and Rafal (1996) found that while patients were unaware of features on the left side of the figure they perceived the figure dependent on features at both ends of the stimulus. In Ro and Rafal’s study, bisection of the Judd figure was as much influenced by neglected features on the left as by perceived features on the right. Mattingley and colleagues found normal illusory effects with patients with stimuli containing both unilateral right sided and bilateral fins. Both studies suggest that the effect of the illusion is due to preattentive processes, the perceptual mechanisms responsible for coding elementary visual features.

The next question to address is whether making a manual response to the visual illusion influences the accuracy of midpoint judgement. Post and Welch (1996) had participants reach for without touching (open-loop) the midpoint of a Judd figure, using their mental representation of its locus to guide their actions. When reaching to the midpoint of the Judd figure was compared with reaching to the mental representation of the midpoint of a control figure (horizontal plain line) the misperception of the midpoint on the Judd was significantly displaced in the direction of the arrow tail of the figure. Reaching errors were calculated by subtracting target (veridical midpoint) location from the median reaching response for that target for each participant. The main effect of target location was statistically significant.

Ellis, Flanagan, and Lederman (1999) examined the growing body of evidence (for example Milner & Goodale, as cited in Ellis et al.) suggesting that the aspects of visual information most often used for visually guided action are distinctly different from those used for visual perception. Using the Judd figure, they had participants perform both a perceptual task and a motor task. In the perceptual task, the experimenter moved a tape above the length of the Judd arrow shaft until the participant said the tape's position was in the center of the shaft; in the motor task, the participant was asked to lift the shaft in the center. In the perceptual task, midpoint judgements on R and L pointing arrows displaced from the veridical midpoint were significant, however this was also the case in the motor task. Linear regression showed 44 % of the variance in grasp could be predicted by the visual estimate of the shaft's center, offering support for a partial dissociation between visual perception and visually guided action. The authors suggest that for this task, the motor system has access to both the illusory perceptual information of the ventral stream (in inferotemporal cortex for ‘what’ features) and the veridical information of the dorsal stream (in parietal cortex for ‘where’ features). It is these authors’ suggestion that the motor system then integrates these two streams of information to direct an initial compromise solution to the output program, which is modifiable with repeated experience.

A problem with the Ellis et al. (1999) conclusions was noted by Mon-Williams and Bull (2000) who questioned why the dorsal stream would have access to more veridical information regarding the center of an object than would the ventral stream. They suggested that the Ellis et al. results could be explained without resorting to the proposals involving the two visual streams. They pointed out that in the reaching task, the effect of the illusion was reduced by partial occlusion of the background caused by the reaching arm. These authors replicated the Ellis et al. study with an additional component of a third task in which participants reached underneath a table on which the Judd figure was placed and indicated their perception of its midpoint without occluding the image. While the effect of the illusion was larger in the open-loop (unseen hand) condition than in the verbal condition the difference was not statistically significant; however, the difference between the action in the closed-loop (seen hand) and open-loop condition was reliably different. In conclusion, they argue that the partial occlusion of the illusion allows the nervous system to better gauge the center of the arrow shaft. As with normal individuals, patients with USN seem to benefit from on-line feedback (closed-loop). In a single case study Edwards and Humphreys (1999) found a patient with USN was able to make adjustments during reach such that grasping of the midpoint of a line or rod was more accurate than the act of pointing to it, which these authors attribute to dorsal stream processes. In the current study participants will be able to see the hand being used to guide the AFF joystick, as well as the joystick, though both are below computer screen level such that no occlusion of the illusion occurs in the manual response.

Having established that the Judd illusion produces a reliable misperception of midpoint judgement in normal individuals and that this misperception persists in the open-loop condition of making a movement toward the midpoint without actually touching the stimulus, it is then possible to use the illusion to examine the effectiveness of training to overcome this misperception.

2. Errorless Learning

Errorless learning involves preventing or minimizing errors from being made during early learning trials, especially the initial trial. The concept of errorless learning was first described by Terrace (1963) in experiments in which he trained pigeons to respond to a stimulus correlated with reinforcement (S+), a red typewriter key, which he called "correct responses" and not respond to a stimulus correlated with non-reinforcement (S-), a green typewriter key, which he called "errors." He disputed the general acceptance of responding to S- as a necessary condition for discrimination learning to occur. To minimize errors, changes were made from the S+ to the S- when the pigeons in the errorless condition were not in a favorable position to strike the typewriter key, such as when the head was turned away from the key. The experimental groups were divided into four training formats: early-progressive S- introduction, early-constant S-introduction, late-progressive S- introduction, and late-constant S- introduction. “Progressive” describes a fading in of typewriter key color from dark to bright green, while “constant” describes the key color remaining at full brightness from beginning to end of training. In both his experiments, the birds in the early-progressive group went through the transition from the S+ to the S+ - S- condition with no responses to the S-, whereas all of the birds in the other groups emitted at least one burst of responses to S- during the first session of the second S+ - S- series. One of the interesting observations in this experiment was that the pigeons in the errorless (early-progressive) group showed behavior that was less agitated at the end of training than those in the other training groups in which errors were allowed to occur. While the birds trained errorlessly lowered themselves away from the key when the S- appeared and waited until the S+ appeared, the behavior of the birds in the other experimental groups included flapping their wings, stamping on the floor of the chamber, and orienting themselves away from the key, with occasional sporadic key-pecking responses to S-. This technique has also been successfully used to teach individuals with profound learning disabilities. In an experiment similar to Terrace’s, Sidman and Stoddard (1967) taught learning disabled children to discriminate between circles and ellipses.

For errorless learning to be successful the procedures need to be foolproof, with learning tasks kept simple, guessing discouraged, and correct responses provided before the individual has a chance to make an error. Techniques employed to prevent errors from being made include: “forward chaining” in which the first step of the task is learned correctly before the second and subsequent steps are taught; “backward chaining” in which all steps of the task are completed with prompts followed by gradually withdrawing prompts from the last step then subsequent steps in reverse order of their occurrence in the task; and "vanishing cues" similar to backward chaining in which cues are progressively removed such as in word stem completion where the complete word is presented followed by successive removal of letters at the end of the word. Strand and Morris (1986) compared the efficiency of three discrimination training procedures for learning disabled children using shape discrimination presented on a computer screen. The three types of training included graded stimulus fading, graded prompt fading, and trial and error training. They found no difference in results between the graded stimulus fading and graded prompt fading, but both were significantly superior to the trial and error approach. The training procedures were continued for participants from each of the three groups for two additional problems, which were followed by a trial and error test problem for each group. The pattern of differences between the groups in the number of errors remained significant while the number of trials to criterion decreased.

Beginning in the early 1990's these errorless techniques, found to be successful with profoundly learning impaired individuals, were subsequently successfully applied to the memory rehabilitation of individuals with amnesia as a result of brain injury (Baddeley & Wilson, 1994; Wilson, Baddeley, Evans, & Shiel, 1994; Wilson & Evans, 1996). While people with intact cognitive abilities are able to learn from their mistakes, research in the field of cognitive rehabilitation with memory impaired individuals has demonstrated that conscious awareness during learning is important for error correction to occur (Baddeley & Wilson). For many individuals with brain injury, this conscious awareness, or memory of the event, is not available to them. Therefore, when errors are allowed to occur during learning, the incorrect responses are often unconsciously remembered and repeated. In a number of studies errorless learning has been found to be superior to trial and error learning for memory impaired individuals (Baddeley & Wilson; Wilson et al.; Wilson & Evans). In a series of single case studies comparing errorful and errorless learning with amnesic participants, errorless learning consistently resulted in superior performance, including assisting a stroke patient to learn the names of people (Wilson et al.). This success may involve a "cost," however. Parkin, Hunkin, and Squires (1998), in a single case study with a patient who had become dysnomic following herpes simplex encephalitis, used errorless learning first to teach the names of politicians he had forgotten, then the names of personal friends he could not remember. While the errorless learning was successful, and the training on personal names was not stimulus bound to the photo used for each name, an unexpected finding occurred. After training on the forgotten politicians' names, he was no longer able to produce names previously generated before training. The authors attributed this retrieval inhibition of previously known information to suppression of other information in the same category, possibly as a means to allow new learning to take place in a system with compromised capacity.

In addition to the single case studies, there have been group studies where the performance of both young and elderly normal control participants are reported. Baddeley and Wilson (1994) report a study using a word stem completion task with three groups of participants: amnesic patients, young controls, and elderly controls. In all three groups the material learned errorlessly was significantly greater than that learned through trial and error, however, both of the control groups were near ceiling at baseline. In both the amnesic and elderly groups, the rate of forgetting was significantly less for material learned errorlessly than that learned errorfully. In a subsequent study, Evans et al. (2000) report in nine experiments with amnesics that errorless learning is the superior method of learning for tasks and situations dependent on retrieval of implicit memory for the learned material, such as learning names with a first letter cue. However, tasks requiring the explicit recall of novel associations, such as learning navigation routes or how to program an electronic memory aide, are more successful with the trial and error technique. It is important to note in this study that the test trials for route learning and electronic aide programming were quite different from the errorless learning trials in as much as all response constraints were removed forcing participants to rely on their impoverished explicit memory similar to the errorful condition. Nonetheless, these results suggest that errorless learning is not a "one size fits all" solution.

Studies of errorless learning with normal individuals have not been limited to control groups for studies with amnesic patients. Prather (1971), in a study examining trial and error versus errorless learning with 96 student pilots on a range estimation task (simulated strafing runs), found trial and error training to be superior to errorless training in transfer of learning and response to stress (electric shock). He found that the trial and error participants were more actively involved in the learning situation, while the errorless participants were more passive. This task was not a simple discrimination between a S+ and S- as was the case with Terrace (1963) and others, but rather one that occurred along a continuum and involved complex perceptual-motor learning. It is important to note that, even though none of the participants was experienced in the experimental task, each was a “moderately experienced pilot who had received his wings in a USAF flight-training program” (p. 378) which would involve prior experience with estimating range between himself in the aircraft and other objects such the ground every time a plane is landed. The author also acknowledges that “most adults have such a long history of trial-and-error learning; they probably have learned to be efficient at this process and may be able to set up their own intrinsic cues in a complex discrimination, cues more efficient than an experimenter or educator could extrinsically provide” (p. 384). It is also important to note that the “stress” inducer, electric shock, is not analogous to the types of stress a pilot might actually experience in the midst of battle. Giving a dual task, where cognitive capacity was challenged, would more closely approximate the type of decision making “under fire” required of a pilot. The author concludes by cautioning against the indiscriminate use of errorless procedures for teaching complex tasks.

In the sport and exercise science literature the effectiveness of errorless learning has been examined through the implicit learning of motor skills involved in athletic performance (Maxwell, Masters, Kerr, & Weedon, in press; Masters, 1992; Liao & Masters, in press). The typical “coaching” technique is described as one of explication of the rules of skill acquisition followed by the learner’s ability to explicate those rules. This is referred to as a hypothesis testing process in which trial and error learners correct their errors during learning by accruing a pool of verbalizable rules that are tested through ongoing sensory feedback about their performance. Maxwell and colleagues challenge the assumption that the acquisition of motor skills proceeds from explicit to implicit learning over the course of skill acquisition. Implicit learning of motor skills involves the acquisition of a skill without a corresponding increase in verbal knowledge about the skill, such that the learner is unable to test hypotheses or identify crucial aspects of skill performance. Instead, the implicit learner passively aggregates all task relevant information or action-outcome contingencies leading to a large knowledge base that is not easily verbalized (Masters). In a study training novice golfers to putt, the errorless group performed their initial putts 25 centimeters (cm) from the hole while the errorful group began 200 cm from the hole. The errorless group gradually moved farther from the hole through a series of eight discrete distances while the errorful group moved closer through the same distances until each was at the same distance as the other group's initial starting point. A third group was moved through all eight distances in random order. Each of the groups was tested for retention, secondary task transfer, and novel distance (300 cm). The errorless group's retention and secondary task transfer, both at 200 cm, was significantly greater than the other two groups, as was their performance in the novel distance transfer task at 300 cm. These findings were consistent with Wulf, Shea, and Whitacre (as cited in Maxwell et al.) who had participants perform a ski simulation task with or without physical guidance and reported similar benefits from guided learning where errors are reduced. These findings are contrary to those of Prather (1971), who did not use novice pilots and may have induced stress by training participants with a learning technique antithetical to their prior training on a skill acquisition task (range estimation) which, though the task itself was unfamiliar, was routine to learning to pilot an aircraft. This then raises the question of whether a skill previously learned through trial and error methods can subsequently be relearned errorlessly, however that is not the focus of the current study.

Guided movement to prevent errors in motor relearning has been successfully utilized by physical and occupational therapists with success in treating patients with physical limitations for many years (Butler, 1992; Butler & Major, 1992a; Butler & Major, 1992b; Butler, Thompson, & Major, 1992). In physical rehabilitation the abnormal gait of children with cerebral palsy has benefited from fixed ankle-foot orthoses (AFOs) that do not allow the typical hyperextension error during gait to occur. The long-term success of this technique, after the fixed AFOs have been removed, has been attributed to allowing appropriate motor learning to occur as a result of correcting the biomechanical environment (Butler et al.). A similar approach has been used in training motor impaired individuals who have posture and balance problems. Biomechanical control of the environment, such that only one segmental joint is targeted for training while the remaining involved joints are kept immobilized, prevents learning incorrect movements (Butler & Major, 1992b). This type of targeted learning of motor control is analogous to the 'chaining' procedures previously described.

3. Active Force Feedback for Guiding Responses

An active force field (AFF) is a controlled relationship between force and position in space which can be used to guide a person's movements and which can be continuously adapted to represent a changing environment and/or task. The AFF joystick used in this study moves in pitch (forward and backward) and roll (side to side) with the force field characteristics mapping an active force field over part of the surface of a sphere. It operates by measuring the force applied by the operator then moving to the appropriate position as determined by an adaptable force-feel characteristic which controls the resulting position to meet a specified relationship between force and position.

The AFF joystick can be used to guide an individual's actions in a limited range. In the context of aircraft, this apparatus's original application, one use is to predict the optimum pilot inputs for flight around obstacles while keeping within flight envelope limitations. This requires an interaction between the user's hand position and the applied force, which is the principle being implemented in the current study in which AFF guided errorless learning is being used to train or correct perceptual judgements in normal elderly individuals.

The AFF system, in as much as it is programmable to move automatically and perform specified tasks (constrain movements to a specified trajectory), functions as a robot. Rehabilitation robotics, a discipline with its origins in engineering, has mushroomed in the last two decades both as a replacement for absent or diminished motor function and as a means of improving residual motor function. Robots have been developed as replacements for a variety of functions such as the Helping Hand Electro-Mechanical Arm that serves as an interactive aid for performing activities of daily living (ADL's) and vocational activities (Sheredos, Taylor, Cobb, & Dann, 1996), mechanical fingerspelling hands for individuals who are deaf-blind (Jaffe,1994), robotic workstations for the severely physically handicapped capable of performing ADL's and vocational tasks (Hammel, Van der Loos, & Perkash, 1992), semi-autonomous wheelchairs (Borgolte, Hoyer, Buehler, Heck, & Hoelper, 1998), and a force sensor robot for use as a walking aide for the elderly (Suzuki, Masamune, Ji, Dohi, & Yano, 1998). Robots are being used therapeutically in physical therapy for exercise, to develop muscle strength and endurance, skill training, to build sensorimotor integration and coordination, and to provide augmented feedback or for tailoring the level of exercise to a patient's movement capability (van Vliet, & Wing, 1991). Examples of therapy augmentation devices include artificial muscle manipulators (Noritsugu & Tanaka, 1997), active impedance controlled treadmills (Tani, Sakai, Koseki, Hattori, & Fujie, 1997), and in virtual environments with haptic feedback for the treatment of motor dexterity disabilities (Prisco et al., 1998).

With regard to robotics being used with stroke patients, these devices have most often been developed to measure impairment and to rehabilitate motor function. For example there are rehabilitators that might be used with stroke patients to accurately measure post-stroke impairment and augment or substitute for some manual therapeutic aspect of traditional physical and occupational therapy (Reinkensmeyer, Dewald, & Rymer, 1996). A robotic arm exercise system for movement-pattern therapy with stroke patients that provides power assistance to enhance movements has been developed (Erlandson et al., 1989). Such a system provides reproducible treatment and continuous feedback to patients. Other robot designs include: a pneumatically powered and controlled robotic orthosis for the purpose of arm rehabilitation and testing for stroke patients (White, Schneider, & Brogan, 1993); a robotic system which applies forces to the paretic limb during passive and active-assisted movements (Lum, Van der Loos, Shor, & Berger, 1999); and a robot to provide muscle reeducation movement patterns after stroke (Dijkers et al., 1991). A group at the Massachusetts Institute of Technology has developed the MIT-Manus robot designed to provide interactive, goal-directed motor activity for clinical neurologic applications and has focussed much of their work on stroke patients (Aisen, Krebs, Hogan, McDowell, & Volpe, 1997). They have subsequently reported that robot-aided therapy does not have adverse effects, that patients have tolerated the procedure well, that peripheral manipulation of the impaired limb may influence brain recovery (Krebs, Hogan, Aisen, & Volpe, 1998), and that at three years follow-up, stroke patients treated daily with additional robot-aided therapy during their acute rehabilitation had improved outcome in motor activity at discharge compared to a control group that received only standard acute rehabilitation treatment (Krebs et al., 1999).

Thus far robots developed for the treatment of stroke patients have all been designed to evaluate or restore motor function. None has addressed cognitive function such as perceptual motor processes. For example, prior to Connor and colleagues (1999) presentation at the International Conference on Rehabilitation Robotics (ICORR '99) restoration of cognitive function had not been addressed in the field of rehabilitation robotics. However, for the biannual ICORR meeting in 2001 the goal of the conference is "to close the gap between high technology and accessibility for people having lost their independence due to the loss of physical and/or cognitive capabilities."

While the robotic device designed by Plegie, Barner, Agrawal, and Rahman (1999) does not address cognitive function, it utilizes the robotic technology incorporated in the present study, that of force feedback. Pledgie and colleagues have designed a non-adaptive force feedback tremor suppression system that achieves a specified reduction in tremor energy, while collecting position, rate, and acceleration feedback. It is important to note that nowhere in the literature has AFF technology been used to implement errorless learning of cognitive or motor functions. However, for any learning program based on the participant using movement to select the correct option from a set of alternatives, the AFF joystick can be set to guide or shape the individual's movement to the correct choice through biodynamic feedback and proprioceptive compensation (Connor, Dee, & Wing, 1999). Such a system offers a time and labor saving device while reducing the potential for human error inherent in having the trainer guide the learner's movement, as well as being adaptable to the individual needs of each user. In addition, since the user's movements are being constrained during training, and because the movements are taking place in three-dimensional space, the technique makes it possible for users to make more realistic movements during learning.

4. The Role of Implicit and Explicit Memory in Errorless Learning

Memory for that which is learned errorlessly has been most often attributed to implicit memory processes, though there has been recent research suggesting that at least memory for certain semantic material learned errorlessly by amnesics is due to preserved explicit memory (Hunkin, Squires, Parkin, & Tidy, 1998). Generally, acquiring new memories progresses through a three stage process beginning with sensory memory involving both a sensory register that briefly maintains information and selective attention which controls its transfer to short term memory. Short term memory or working memory constructs and updates internal models while organizing and integrating information for problem solving and decision making. This process is generally associated with activity in the hippocampus and surrounding cortical regions of the parahippocampal gyrus, perirhinal and entorhinal cortex. The hippocampus then keeps memory traces for short periods of time (Squire, 1999). For most memories to be retained, they must be encoded into long term memory and be capable of being recalled from that memory store found in various regions of the neocortex (Bernstein, Clarke-Stewart, Roy, & Wickens, 1997).

Long-term memory is further categorized as either declarative (explicit or conscious) or nondeclarative (implicit or nonconscious). Explicit memory may either be semantic consisting of general knowledge or episodic for specific events. Implicit memory includes the categories of procedural for skills and habits, priming, perceptual for motor skills, classical for paired associations, and non-associative for habituation.

The neuroanatomical subsystems involved in explicit and implicit memory are physically distinct, which helps to explain why amnesics often have preserved implicit memory while having impaired explicit memory. The substrate of explicit memory is found in the medial temporal lobe and diencephalon. Implicit memory involves other cortical and subcortical areas dependent on the type of memory. While procedural memory is associated with the basal ganglia (BG), predominantly the caudate nucleus and striatum, priming and perceptual learning, and non-associative memory are dependent on neocortical areas particularly of the visual system related to perception (Squire, 1999). For example in a study reported by Squire, patients with Parkinson’s Disease, associated with damage to the BG, made no progress on a habit learning task while being quite capable of remembering what they had done during the learning trials.

Masters, MacMahon, and Pall (in press) found, when Parkinson's patients were trained implicitly using errorless learning in a simple motor task, hammering, there was no difference between the EL and EF groups once the guidance was removed from the EL group. However, when given a dual task (counting backwards by ones from 200) the EF group's performance became significantly worse, while the EL group's performance was unchanged, which is attributed to the EL group not needing to make use of the resources of working memory to execute the hammering task.

Baddeley and Wilson (1994) proposed that one of the major functions of explicit memory is the elimination of learning errors, and it is facilitated by devoting full attention to the material to be remembered. In contrast, responses based on implicit memory are dependent upon emitting the strongest response. If erroneous responses are allowed to occur they are then strengthened across repeated learning trials. For a comparison of trial-and-error and errorless learning with both amnesic and normal participants these authors used a stem completion task which involves priming, an implicit memory process. Errors were "injected" into the early phase of learning for the trial-and-error group and were prevented from being made with the errorless group. In the errorless group, the young controls were near ceiling throughout, while the elderly started close to the performance of the amnesic group but by the final block of training trials were performing near ceiling with the young controls. In the errorful group, all three groups began the early trials well below the performance of their counterparts in the errorless group but after three blocks of training trials the young and elderly groups were again near ceiling while the anmesic group had made little gains. This study did not address the effect of either type of learning on retention following a delay. Hunkin and colleagues (1998) conducted a similar experiment with amnesics using both errorless and errorful learning techniques. They, however, did follow up after a 48-hour delay using both free recall, requiring explicit memory, and cued recall, dependent upon implicit memory. They found the participants trained errorlessly outperformed those trained errorfully, though there was a substantial decrement in the performance of the errorless group after the delay, that decrement was significantly greater for the errorful group. These authors concluded that the benefits of errorless learning in their paradigm were a result of the effects of error prevention on residual explicit memory rather than implicit memory. Evans and colleagues (2000), however, were unable to replicate this study, with most of their results showing no effect in the free recall condition.

Whether errorless learning is dependent upon implicit memory, explicit memory, or both is relevant to training normal individuals, particularly for tasks performed under the stress of cognitive demands as discussed in the sport and exercise science literature. The implications for the elderly of which memory processes are recruited during training are even greater as implicit memory has been shown to be more resistant than explicit memory to the effects of normal aging (Bernstein et al., 1997).

5. Normal Cognitive Changes with Aging

It is well documented that with increasing age every organ system alters to some degree, and this is certainly true of the brain's cognitive functioning in the normal elderly. While the documented changes in brain structure and behavioral measurements thus far have shown low-level correlations and equivocal findings, this is more likely due to classification of who is considered “older” or elderly and the “normality” of some elderly volunteers. While some studies of older persons may include participants in their 50’s, others may begin classifying people as “older” at age 60 or 65. Interestingly, both cognitive and physiological changes occur with increasing rapidity in the age range of 50 to 65. Yet, age ranges that are overly inclusive may mask gradations of change that are rapidly occurring and thereby spuriously inflate the interindividual variability of the measure or measures of interest (Lezak, 1995). For example, in the stroke study for which the current study will provide normative data, the mean age is 60 and the range is 34 to 83. It is also the case that the “normality” of some apparently healthy and intact volunteers, if examined extensively, would reveal early or subtle signs of brain disease that otherwise remains undetected in studies of normal aging, accounting for further interindividual variability. This variability is influenced by life style and health, emotional status and life-long habits and interests (Lezak). The patterns of cognitive aging will be examined with regard to sensory and motor changes, attention, memory, visual perception, reasoning, and overall health.

Sensory and motor changes. All sensory modalities decline in sensitivity and acuity with age, with response times becoming increasingly slowed and fine motor movements becoming less precise. Visual acuity and oculomotor functions begin to show decline during the age range of 40 to 50 such that by age 60 and older most individuals experience multidimensional visual compromise. This decline tends to progress rapidly after the age of 60 and is accompanied by visual deficits in decreased scanning efficiency. Visual decline is accompanied by decline in audition, which decreases rapidly in the ages of 50 to 60 and later. Older individuals may also have difficulty with both speech discrimination and sound localization (Lezak, 1995).

Aging is characterized by a slowing in all aspects of behavior. Simple reaction times begin to follow a regular pattern of gradual incremental slowing beginning at age 30. While by age 60 there may be a drop of no more than 20% in reaction time rate relative to performance in the 20's, there continues to be a decline at about the same steady rate. This decline is evidenced in longer preparatory intervals accounting for an increasing disparity between young and older adults. By contrast, the speed with which complex activities involving mental processing takes place shows a rapid rate of slowing from the 60's onward. Demographic and health variables influence response speed with age having the most pronounced influence with men responding more quickly than women and well educated individuals being faster than those with average or less education. When performance slowing is analyzed in the elderly, mental processing appears to be the most important component since slowing tends to occur at decision points and in initiating and redirecting movements, though the movements themselves are not significantly slower in this group. Slowing contributes to the lower scores typically obtained by older persons on timed tests of cognitive functions such as Block Design and Digit Symbol tests in the Wechsler Intelligence Scales (WIS). Both diminished dexterity and coordination in the elderly affect fine motor skills, while motor strength begins to decrease somewhat around the 40's with accelerated losses thereafter (Lezak, 1995).

<u>Attentional capacity.</u> The effects of age on attentional efficiency, though connected with processing speed, varies with the complexity of the task or situation.

Simple attention span, which is considered a measure of short term or working memory, remains intact into the eighth decade, with concentration holding up as well. However, when divided attention is called upon, elderly individuals respond more slowly, make more errors, or both such as in choice reaction times or dual tasks (Lezak, 1995). Given this pattern of decline in attentional functions, it could be reasoned that in the learning process, elderly would benefit from implicit learning strategies. When their conscious cognitive processes are otherwise engaged during perceptual motor learning, as has been suggested in the sport and exercise literature (Masters, 1992; Liao & Masters, in press; Masters, Polman, & Hammond, 1993) and in the Parkinson's disease literature (Masters et al., in press), performance of the elderly could be expected to be more resistant to breakdown under the stress of competing cognitive demands.

Memory capacity. Memory and learning in the elderly may be viewed along an information processing continuum with automatic or overlearned processes being at the easy age-resistant end while effortful and more difficult learning and memory are at the more age vulnerable end. Regardless of age, short-term retention both with and without interference follows a similar pattern of diminishing recall with increased learning load and duration of interference. Short term memory is influenced by aging when the task requires mental manipulation of material as is involved when trying to remember material while engaging in another activity. Overall learning ability decreases with age, with losses being particularly evident when measured by recall. Visual memory is particularly vulnerable to age, whether examined by recall or recognition, as it is compromised at an earlier age than verbal memory. Once material is encoded, however, rates of forgetting for visually presented material remain the same for younger and older individuals (Lezak, 1995).

Visual spatial ability and reasoning. Visual perceptual judgement for spatial and nonspatial stimuli declines steadily from the age of 65 onward, with concomitant difficulty in visual perceptual organization. While on Block Design, a constructional test, the factor of time is most closely associated with aging than any other performance variable, even when untimed, aging takes its toll due to the novelty and spatial nature of the task as well as its solution-seeking requirements. While reasoning regarding familiar material fares well with aging, when it is brought to solving unfamiliar or complex problems older individuals' performance declines increasingly with age. Mental inflexibility may occur when tasks become more difficult such as under increasing memory load or increased complexity. Tasks dependent on frontal lobe functioning are more vulnerable to aging as is evidenced in increasing perseverations and difficulty withstanding distractors (Lezak, 1995).

Health and cognitive aging. Cognitive functioning in the elderly is positively influenced by health status and negatively influenced by the kinds of systemic diseases normally associated with aging such as cardiovasular disease, hypertention, and diabetes. Nutritional requirements and metabolism change in the elderly. Often the undernutrition for substances important to cognitive functioning are not adequately replaced in the diet. Alternatively, the cognitive speed and efficiency in the elderly has been shown to positively benefit from regular cardiovascular exercise, as has overall visual functioning. This effect is likely due to the increased cerebral blood flow occurring with exercise that leads to better oxygenation of the brain. Activities such as playing video games may be beneficial as a mental exercise which can increase reaction time, as well (Lezak, 1995).

The Present Study

The purpose of the present study is to establish baseline information for normal elderly individuals on a perceptual motor learning task, line bisection of the Judd Arrow (Judd, 1899), utilizing a computer and joystick, to implement errorless and errorful training. In doing so it is possible to examine the effects of errorless (EL) and errorful (EF) training on both efficiency and retention of learning, as well as resistance to the effects of increased cognitive demands. It will also be possible to examine the correlation between age and the neuropsychological measures of interest and the acceptance of computer aided learning by older individuals. While a number of published reports have examined implicit and explicit learning and aging, thus far there has been scarce information in the literature specifically addressing errorless learning in normal elderly individuals. This study will specifically examine which method of learning is more efficient on the Judd Arrow perceptual motor task in an elderly population, errorless or errorful; which method of learning is retained better after a one week delay; and which method of learning is more resistant in both accuracy and response speed to the effects of increased cognitive demands.

The following hypotheses will be tested:

1. Errorless learning is a more efficient method of learning midpoint accuracy on the Judd Arrow perceptual motor task.

2. Retention of accuracy on the Judd Arrow perceptual motor task is significantly greater with errorless learning.
3. Accuracy is more resistant to the effects of increased cognitive demands with errorless learning.
4. Response speed is more resistant to the effects of increased cognitive demands with errorless learning.

Method

Participants

Forty-three independently living normal elderly male and female participants, ranging in age from 60 to 77, all from the West Midlands, United Kingdom were recruited for this study and will be described as the recruitment sample. These individuals were all community dwelling normal elderly recruited through the following sources: University of Birmingham, School of Psychology elderly panel volunteers, individuals from the community who volunteer to participate in studies within the department when normal elderly are needed; retirement housing in the community for independently functioning elderly; churches; community organizations and recreation facilities for the elderly. Participants represent a convenience sample.

Sample

All individuals in the study met the following criteria: 1) age 60 years and over (no upper limit); 2) able to give informed consent; 3) primary language is English; 4) no current or prior history of acquired brain damage; 5) no prior history of psychiatric illness; 6) no current or prior history of alcohol or other drug abuse; 7) has motor ability to use dominant upper extremity to move a joystick; 8) has no visual impairment that would preclude seeing visual stimuli presented on a computer screen; 9) has no auditory impairment that would preclude hearing amplified computer generated tones. The study did not exclude participants who might have early signs of a dementing condition but who had not been diagnosed and who were living independently in the community.

Assignment

Participants were randomly assigned to either the control group or experimental group. Numbers from one (1) to sixty (60) were placed in a container and each participant drew a number. Odd numbered participants were assigned to the control group and even numbered participants to the experimental group. Twenty-three participants drew odd numbers and 20 drew even. The control group received EF training and the experimental group received EL training. Both groups were given a cognitive loading task, requiring mental manipulation of information, during the final training session.

Measurement

The purpose of this study was to establish normative data on the use of response guided errorless learning within the normal elderly population. The following data was obtained for each participant: gender and handedness as well as demographic data about age and education in years. Potential covariates were determined through neuropsychological assessment which included intellectual functioning, memory, and attention. A *z* score was calculated for each of the three neuropsychological categories. Intellectual functioning was determined by obtaining a *z* score for the combined scores on the National Adult Reading Test (NART-2: Nelson & Willison, 1991) and the Wechsler

Adult Intelligent Scale-Revised (WAIS-R: Wechsler, 1981) Block Design (BD). Attention was determined by the combined scores from the WAIS-R Digit Symbol (DSy), WAIS-R Digit Span (DSp), and the Trails A and B Test (TMT: Army Individual Test Battery, 1944). When an individual's speed on Trails B was slower than a *z* score of – 3.0, a maximum score of – 3.0 was assigned to avoid skewed data. Memory was determined by performance on Visual Reproduction I (immediate) and II (delayed) on the Wechsler Memory Scale-Revised (WMS-R: Wechsler, 1987). The presence or absence of depression was measured by the Geriatric Depression Scale (GDS: Spreen & Strauss, 1998), with not depressed defined as a score of nine or lower.

The Table 1 provides descriptive information about the recruitment sample's age, education, and *z* scores for intelligence, memory and attention. These mean *z* scores, which are above the population mean ($z = 0$), suggest higher functioning individuals were more likely to volunteer for the experiment. It is useful to note in the United Kingdom the age at which individuals exit the state school system, if not going on to university training, is 16. Therefore ten or eleven years of education, depending on age at entry, would represent completion of standard secondary school training.

Table 1

Demographic Characteristics of the Recruitment Sample

Descriptive Statistics						
	N	Mean	Std. Deviation	Minimum	Maximum	Range
AGE	43	67	4.59	60	77	17
EDUC	43	12.19	3.33	9	22	13
z score Intelligence	43	0.89	0.79	-1.10	2.03	3.13
z score Memory	43	1.15	0.93	-1.31	2.63	3.94
z score Attention	43	0.23	0.86	-2.35	1.52	3.87

Independent Variables

The experimental factors in this study were type of training (EF or EL) and phase of training (pre and post for first and second sessions, and dual task in second session).

Dependent Variables

One dependent variable was number of training trials required to reach criterion in each of the two training sessions, with criterion set at a *z* score of 1.15 such that 75% of each block of post-training arrow bisections would be within one standard deviation of the individual's pre-training mean midpoint judgement on the horizontal lines. Other dependent variables were accuracy of arrow bisection judgements, determined in mm distance from the true midpoint with the positive error always in the direction of the tail end of the arrow, response speed as a result of training, and the effect of the dual task on both accuracy and response speed. These variables were examined for each participant and compared by group.

Instruments

All participants received a Participant Information Sheet and a Consent Form (see Appendix A, B). The inclusion information was obtained for each participant (see Appendix C). Female participants were asked if they are on estrogen replacement therapy (ERT) since it has been shown to have protective effects on memory, including short-term visual memory and visual perception (Costa, Reus, Wolkowitz, Manfredi, & Lieberman, 1999; Duka, Tasker, & McGowan, 2000; Resnick, Maki, Golski, Kraut, & Zonderman, 1998; Resnick, Metter, & Zonderman, 1997). Table 2 provides information in the recruitment sample about the gender, handedness, use of hormone replacement therapy and incidence of depression, as measured by the Geriatric Depression Scale described below.

Table 2

Self-Report Characteristics of the Recruitment Sample

Descriptive Characteristics		
	M	**F**
Gender	16	27
	R	**L**
Handedness	39	4
	Y	**N**
HRT	3	40
Depressed	7	36
Total Sample = 43		

All clinical assessment was completed prior to the beginning of training. Each individual completed the Geriatric Depression Scale (GDS: see appendix D), also known as the Mood Assessment Scale, a screening instrument to measure depression in the elderly for which there is no commercial source (Spreen & Strauss, 1998). The GDS consists of 30 yes/no questions designed for self-administration and takes about 5-10 minutes to complete. The recommended cutoff scores are: normal, 0-9; mild depressives, 10-19; severe depressives, 20-30. Means for normal elderly are reported to be 2.5 (SD = 2.29) for ages 60 to 72 and 3.2 (SD = 3.67) for ages 73 to 85. Factor analysis establishes a major factor of dysphoria and minor factors of worry/dread/obsessive thought, and of apathy/withdrawal. Internal consistency is reported as .94 and split-half reliability as .94, and test-retest reliability after one week of .85 (Spreen & Strauss). This test was selected because of its brevity, availability of normative data for the target population of this study, and for its statistical properties.

The NART-2 (Nelson & Willison, 1991) was selected as a measure of overall ability level particularly since vocabulary tends to resist the dementing process better than any other intellectual attainment. The test is comprised of 50 phonetically irregular words which the individual must pronounce. It is one of the most reliable tests in clinical use with internal consistency reliability estimates above .90 (Spreen & Strauss, 1998). Tests in the United Kingdom show the IQ score derived correlates significantly with education (r = .51) and social class (r = .36), but the - .18 correlation with age, though significant, accounts for none of the variance. Split-half reliability coefficient, when scoring for errors, is .90, interrater reliability coefficients between .96 and .98, and test-retest reliability coefficients of .98. Factor analytic studies comparing the NART and WAIS identify the primary factor as verbal intelligence (Lezak, 1995).

Three subtests from the WAIS-R (Wechsler, 1981) were selected to measure discrete aspects of performance: Digit Span (DSp), Block Design (BD), and Digit Symbol (Dsy). Norms are available for up to age 90 and above for each of these subtests making them well suited for an elderly population (Spreen & Strauss, 1998). The Mayo's Older Americans Normative Studies (MOANS) for the WAIS-R was used for scaled scores and percentile ranges for DSp, BD and DSy (Spreen & Strauss).

Digit Span (DSp) was selected to measure span of immediate verbal recall with digits forward (DF) measuring efficiency of attention or freedom from distractibility and digits backward (DB) adding the component of working memory. DF requires the individual to repeat aloud a series of numbers after the examiner has spoken them beginning with a three number series and progressing to an eight number series, with each level having two sets of numbers. DB requires the individual to repeat in reverse order a series of numbers beginning with two in the series and progressing to eight, again with each level having two sets of numbers. Test-retest reliability coefficients range from .66 to .89 depending on interval length and age. Factor analysis has shown that both visual and verbal processes contribute to the reversed digit span performance (Lezak, 1995).

Block Design (BD) was selected as a measure of constructional performance measuring visuospatial organization and visuoconstructive abilities. On the BD subtest, the participant is presented with red and white blocks and is asked to construct replicas of constructions made by the examiner or of designs printed in smaller scale. BD combines two dimensional visuospatial perception and manual response. In addition, it correlates highly with general mental ability and for this reason is being used as a nonverbal measure of intelligence. Age does reduce performance levels primarily in the speed with which designs are completed however, age-corrected scores are available. Reliability coefficients for BD reported in the WAIS-R manual and based on split-half comparisons range from .83 to .89. Test-retest reliability in an elderly sample was .73 to .84 depending on age and education. Factor analytic studies demonstrate high loadings on perceptual organization and complex intelligence (Lezak, 1995).

Digit Symbol (DSy) was selected to measure visuomotor performance and complex attention, as well as incidental memory. The DSy substitution task consists of rows of blank squares; each with a randomly assigned number (1-9) printed above. A key is printed above these rows showing each number paired with a different symbol. The individual is asked to fill the blanks below the numbers with the corresponding symbol as quickly as possible. Motor persistence, sustained attention, response speed and visuomotor coordination are all important in performance on this subtest, but not visual acuity. The natural response slowing that comes with age is the most important variable contributing to age differential on this test, however, performance is relatively unaffected by intellectual ability, memory, or learning. Test-retest reliability coefficients are in the range of .82 to .88 and remain at these levels or higher for older adults. Factor analysis shows the heaviest loading on perceptual organization. This test is also extremely sensitive to dementia being one of the first to decline and is also a good predictor of the rate at which dementia progresses (Lezak, 1995).

Visual Reproduction I (immediate) and II (delayed) from the WMS-R (Wechsler, 1987) were selected as measures of non-verbal immediate and delayed memory for visually presented material. This subtest consists of four items, three of which contain a single figure and the fourth contains two figures, one with three and the other with two geometric elements. It has the steepest age gradient of all the WMS-R subtests, with the effects of education being small. It has an interrater reliability coefficient of .97. Depending on the age band, internal consistency estimates ranged from .46 to .71 on immediate recall and from .38 to .59 on delayed recall. This subtest correlates significantly with tests involving predominantly visuospatial problem solving and visual memory. Its association with other visual memory tests is stronger for the delay trial (Lezak, 1995). The Mayo's Older Americans Normative Studies (MOANS) for the WMS-R will be used for scaled scores and percentile ranges for Visual Reproductions (Spreen & Strauss, 1998).

The Trail Making Test (TMT: Army Individual Test Battery, 1944) was selected as a test of speed for attention, sequencing, mental flexibility, visual search and motor function. It requires the connection, by making pencil lines, between 25 encircled numbers randomly arranged on a page, in proper sequence (Part A) and of 25 encircled numbers and letters in alternating order (Part B). The TMT has an interrater reliability reported as .94 for Part A and .90 for Part B. One-year test-retest reliability for older participants (mean age 67) has been found to be .64 for Part A and .72 for Part B. Parts A and B correlate only .49 with each other suggesting they measure somewhat different functions, with Part B requiring more visual-perceptual processing ability than part A. However, a low score on Trails B relative to Trails A may reflect increased demands in motor speed and visual search rather than reduced cognitive efficiency. This test loads on factors of visuospatial sequencing and rapid visual search as well as cognitive set-shifting; and Part B also loads on focused mental processing speed (Spreen & Strauss, 1998). Normative studies show performance times increase significantly with each successive decade of age (Lezak, 1995) however, norms are available for elderly populations to age 97 (Spreen & Strauss). In this study two individuals were able to complete Trails B, but with extreme difficulty (participant 13 in 363 seconds and participant 23 in 208 seconds), and one participant was unable to complete the task (participant 54 was discontinued at 257 seconds when unable to progress beyond 4 D in the letter-number sequence). These three participants were given a maximum *z* score of –3.0 to avoid skewing the data set for both groups on the attention variable.

Apparatus

Each participant bisected a series of individually presented horizontal Judd figures, (75 mm x 30 mm) displayed on a computer screen, using a cross cursor moved by an AFF joystick (see Appendix E).

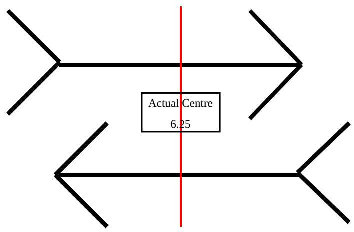


Figure 1. Judd Arrow pointing right and left

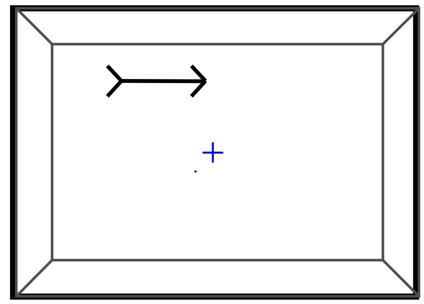


Figure 2. On Screen Task: + cursor is moved to bisect horizontal line of Judd Arrow *using AFF joystick*

Each trial consisted of a single Judd figure presented in any location on the screen, with presentations randomized for left and right pointing arrows during each block of trials. During EL training the AFF joystick defined a force field "valley" within which the cursor could only be moved to the target midpoint. In the EF training force feedback was turned off. Both training conditions included auditory knowledge of results (KR). A pleasant tone sound occurred when a correct response was made and an unpleasant "cluncking" sound occurred on incorrect responses. Participants were introduced to both tone sounds before training began. The "bandwidth" (i.e. region for definition of a correct response) was set at $\pm$ 3 mm ($\pm$ 4% of the horizontal line) either side of the midpoint. There was no KR during the baseline or post training blocks of trials.

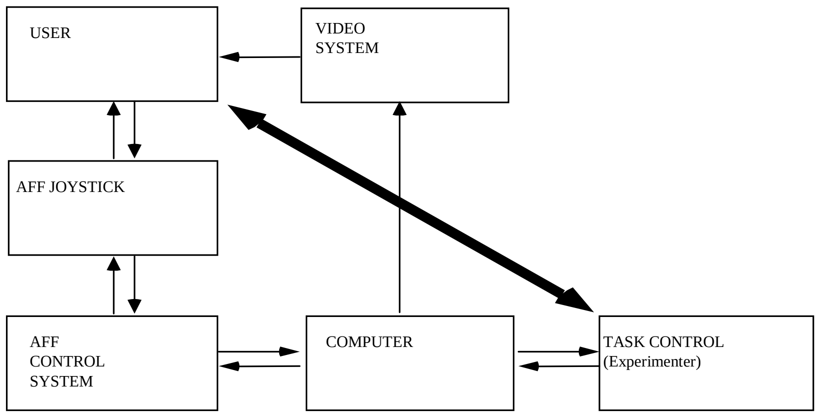


Figure 3. Response guided errorless learning system components. The user responds to video presented information by making movements of the AFF joystick. These are subject to guiding forces produced by the AFF control system with parameters set by the experimenter.

Procedure

Each individual in the study was paid £15 (approximately $22.00) for their participation in the clinical testing and two training sessions. Attrition was mitigated in part by payment for participation at the end of the second and final training session. Only one person did not return for the second session and that was due to illness.

Each participant was administered the clinical test battery. To avoid experimenter bias, the individual who administered the clinical battery did not know group designation and was not the person training participants on the computer equipment. Each participant was assigned to either the control or experimental group depending on the number drawn from the container. During session one, prior to collecting any data on the computer, each participant was given practice using the joystick to move the onscreen cursor to the midpoint of horizontal lines on the screen. Figure 4 in the Complications section below shows the time line for this experiment. Each individual was initially given 5 practice trials, and if more were necessary practice continued until the individual followed instructions correctly for 3 consecutive trials. After practice criteria were met, a pre-training mean for plain line bisection on the computer was obtained. There was one block of 10 horizontal line presentations during which the participant used the joystick to move the cursor on the screen to the midpoint of the horizontal line, with instructions to work as quickly and as accurately as possible. Mean midpoint judgements were calculated for the 10 horizontal lines in mm distance from the true midpoint with errors left of midpoint expressed as a negative number and errors right of midpoint expressed as a positive number.

Once the pre-training mean was established, each individual proceeded to Baseline on the Judd figure. The following procedures occurred in each of the two training sessions. During Baseline, a block of 10 arrows were presented with the instructions to move the cursor to the midpoint of the horizontal line of the arrow using the joystick while working as quickly and accurately as possible.

Baseline was followed in each of the two computer sessions by a training phase consisting of blocks of 16 arrow presentations, each followed by a block of 16 post-training baseline arrow presentations until criterion was met. The instructions continued to be to move the cursor to the midpoint of the horizontal line of the arrow using the joystick while working as quickly and accurately as possible. During each training block of 16 arrows, those individuals assigned to the EF control group received auditory KR on each trial. Those individuals assigned to the EL experimental group were given force feedback in the joystick that prevented them from going to an incorrect midpoint location, in addition to receiving the same auditory KR as the control group.

Each block of 16 training trials was followed by a block of 16 post-training baseline trials to measure performance. During each post-training block of arrows there was no auditory KR or force feedback in the joystick. For both experimental and control groups training continued in each of the two sessions until the participant reached the target criterion. This criterion was based on the individual participant's mean midpoint judgement and standard deviation on the 10 horizontal lines in the pre-training condition. Criterion was set at a *z* score of 1.15 such that 75% of the block of post-training arrow bisections would be within the individual's pre-training standard deviation of their mean midpoint judgement on the horizontal lines. Participants were given a rest, at their discretion, between each block of post-training baseline trials and the subsequent block of training trials until criterion was reached. If criterion was not reached in a single session, training for that session was discontinued after the individual failed to show improvement in *z* score for 3 consecutive blocks of training trials. (See Appendices F, G).

At the end of the second and final session, once accuracy or discontinue criterion was reached, a dual task was given on a final block of 16 arrows to both control and experimental groups. Before proceeding with this final block each individual was asked to say aloud numbers and letters paired sequentially beginning with number 1 and letter A. They were given examples beginning with 1 A, followed by 2 B and 3 C after which they were asked to begin with 3 C and say the sequence out loud stopping them on 6 F. Thereafter they were given the instruction to say the number/letter sequence in their heads while completing the final series of arrow bisections (See Appendix H). Participants were informed that periodically the experimenter would ask them to say what sequence they were on. This occurred three times, at random intervals, during the 16 arrow presentations. They were told to continue to work as quickly and as accurately as they could.

Power and Sample Size

Pilot data on a sample of 10 individuals who received both EF and EL training on the Judd figure computer task was analyzed to calculate effect size, power and sample size (Connor et al., 2000). In the pilot study, each individual received one block of training trials in each of the two training conditions in two separate sessions conducted one week apart. The type of training received in each of the sessions was counterbalanced among the participants. From this study it was possible to examine data for accuracy based on training type. Mean error in pixel distance (1 pixel = 0.4 mm) from the true midpoint was calculated for all 10 participants following training in the EF and EL conditions and the difference used to calculate γ. The standard deviation was pooled between the two training types. Using this information a medium effect size was shown ($\gamma = .49$). With a sample size of 40, participants equally distributed between the control and experimental groups, the power would be .60 for a two-tailed test, $\alpha = .05$. Additional participants over and above the minimum sample size of 40 would increase the power of this study. To achieve a power of .80 in the present study, 66 participants would be needed.

Data Analysis

Prior to running tests of significance, descriptive statistics were calculated on the demographic variables of the recruitment sample used in the study. Means and standard deviations were compiled for each of the participants on each of the instruments used in the study (See Appendix I). Published norms are presented for comparison on each of the clinical instruments used (See Appendix J).

Means and standard deviations were calculated in mm distance from the true midpoint for each individual's pre-training accuracy on line bisection of plain horizontal lines. From this data a z score was calculated for each participant which was used as that individual's training criterion in each of the two training sessions. Criterion was a z score of 1.15 to capture 75% of the post-training observations within one standard deviation of each individual's mean performance on the plain line bisection. Accuracy on the Judd arrows was calculated in mm distance from the true midpoint with the positive direction being toward the open end of the arrow. This method made it possible for the error on both arrow types (right and left) not to be averaged out in the analysis. Therefore, on left pointing arrows the positive direction of error from the midpoint was right of center and on the right pointing arrows the positive direction of error was left of center.

Results were analyzed for accuracy, response speed, and whether criterion was met at final post test at the end of both sessions and at baseline of the second session. No participant was eliminated from the study if criterion was not met. Training stopped for those who did not meet criterion when the discontinue rule was met. Their performance at the discontinue post test was then used in the analysis. One participant (55) met criterion at baseline in session one so did not receive training. However, criterion was not met at baseline in session two resulting in training. Therefore, her baseline session one performance on all measures was used as post test session one performance so as not to loose the data during analysis. Similarly, six individuals (7, 26, 27, 32, 38, 60), two in the EF condition and four in the EL condition, met criterion at baseline session two and their baseline two performance data was used as post test session two performance data.

Complications

Six participants were eliminated from all data analyses resulting in a test sample of 37. Two participants, one each in the EF and EL conditions (participants 3 and 12 respectively), met training criterion at baseline of each of the two sessions. As a result, neither received training at either session so their results were not included. Three participants, all in the EF condition (participants 1, 41, 49), had spurious baseline *z* scores for accuracy due to early computer software difficulties. These individuals did not receive training in session one when they should have so their results were not included. One participant in the EF condition (45) was unable to attend the second session and her results were not included.

Two individuals, both in the EL condition (participants 4, 44) were eliminated from the dual task analyses for both accuracy and response time as they erroneously were not given the dual task. There were additional computer software problems resulting in no response time data being collected in session one for six participants, three each in the EF and EL conditions (participants 4, 25, 28, 30, 33, 55). However, these difficulties were corrected before the second session such that response time data was collected for each of these individuals during the dual task, except participant 4 who was not given the dual task. Figure 4 shows the participants who were not included at each phase in the time line of this experiment.

	Session 1				***Session 2***				
	Practice	**Pre Test**	**Baseline 1**	**Training 1**	**Post Test**	**Baseline 2**	**Training 2**	**Post Test 2**	**Dual Task**
Accuracy	1,3,12,41, 45,29								1,3,12,41, 45,49,4,44
Response Time	1,3,12,41,45,49,4, 25,28,30					1,3,12,41, 45,49			1,3,12,41, 45,49,4,44

Figure 4. Time line of experiment and participants excluded at each phase

Analysis of Hypotheses

Before addressing each of the hypotheses individually, the control and experimental groups were examined for differences between the two groups. There were no differences between the groups on the nonparametric variables of gender, handedness, hormone replacement therapy, and depression as revealed by Mann-Whitney *U* Tests. Similarly, there were no differences between the groups on the parametric variables of age, education, and *z* scores for intelligence, memory, and attention as revealed by independent samples *t*-tests. The two groups were also compared on the performance variables at baseline 1 of accuracy *z* score for combined left (L) and right (R) pointing arrows, mean accuracy in mm distance from the midpoint and mean response time (RT) on L and R pointing arrows using independent samples *t*-tests. Again there were no differences between the two groups, though the pattern of means on L pointing arrows was in the direction of the EL group being more accurate (see Appendix K).

Hypothesis 1—Number of Training Trials Necessary to Reach Criterion

It was hypothesized that EL would prove to be a more efficient means of learning midpoint accuracy on the Judd Arrow as measured by number of training trials required to reach criterion of an accuracy *z* score of ≤ 1.15. This particular measure of performance proved to be insensitive to the differences between the two groups as a result of the experimental design. Since training was discontinued if participants failed to improve their accuracy *z* score after three consecutive training trials, no participant received more than four training trials in either session. Using an independent samples *t*-test, the number of training trials participants in each of the two groups received was not significant (see Appendix L). The means and standard deviations for each group for the two training trials are presented in Table 3.

Table 3

Number of Training Trials by Session

	Training	N	Mean	Std. Dev
No. of training trials session 1	EF	18	2.89	0.96
	EL	19	2.74	0.99
No. of training trials session 2	EF	18	2.28	1.13
	EL	19	2.11	1.24

Another way to examine this hypothesis was to compare the EF and EL groups on numbers of participants who met criterion at the end of session one, the beginning of session two, and the end of session two. Table 4 provides the frequencies for both groups at each of the three phases of training. Using a Mann-Whitney *U* Test these results were found to be non significant (see Appendix M), again because experimental design using the discontinue rule resulted in no one receiving more than four training trials in either session.

Table 4

Number Who Met Criterion by Phase of Training

Participants Meeting Criterion *z* score $\leq$ 1.15			
	post test1	baseline2	post test 2
EF	5	2	6
EL	8	4	7
Total	13	6	13

Hypothesis 2—Accuracy of Midpoint Judgements

Retention of accuracy of midpoint judgments was hypothesized to be significantly greater with EL than with EF. A three factor, two levels per factor, repeated measures ANOVA was carried out comparing Session (1,2) by Phase of Training (pre or post) by Arrow Direction (L, R). Within subjects main effects were found for Phase of Training $F(1, 35) = 20.65$, $p < .01$ and Arrow Direction $F(1, 35) = 18.94$, $p < .01$. Both types of training resulted in improved accuracy in the post test condition as can be seen in the means and standard deviations in Table 5. Participants were more accurate on L pointing arrows than R pointing arrows at baseline and post test during each session. There was an interaction between Session and Phase of Training, $F(1, 35) = 6.53$, $p < .05$, showing that Pre Training accuracy was greater in Session 2 than Session 1 but Post Training accuracy was not improved in Session 2 over performance in Session 1. The pattern of means was in the direction of a three way interaction between Phase of Training, Arrow Direction, and Type of Training with the EL group mean (.76 mm) on left pointing arrows approaching true midpoint $F(1,35) = 3.82$, $p = .059$ and power of .48. There was a between subjects main effect for type of training $F(1, 35) = 5.33$, $p < .05$. Means and standard deviations, collapsed across sessions, for the within subjects main effects and means and standard deviations collapsed across arrow direction in the interaction are presented in Table 5. The interaction between Session and Phase is plotted in Figure 3.

Table 5

			Mean	Std. Error	95% Confidence Interval	
Phase of Training					Lower Bound	Upper Bound
		Pre	3.27	0.23	2.81	3.73
		Post	2.17	0.28	1.6	2.73
Arrow Direction						
		Left	1.99	0.26	1.46	2.52
		Right	3.47	0.3	2.85	4.05
Session * Phase	Phase					
Session	1	Pre	3.72	0.26	3.19	4.25
		Post	2.14	0.32	1.49	2.8
	2	Pre	2.82	0.31	2.19	3.45
		Post	2.19	0.31	1.57	2.81

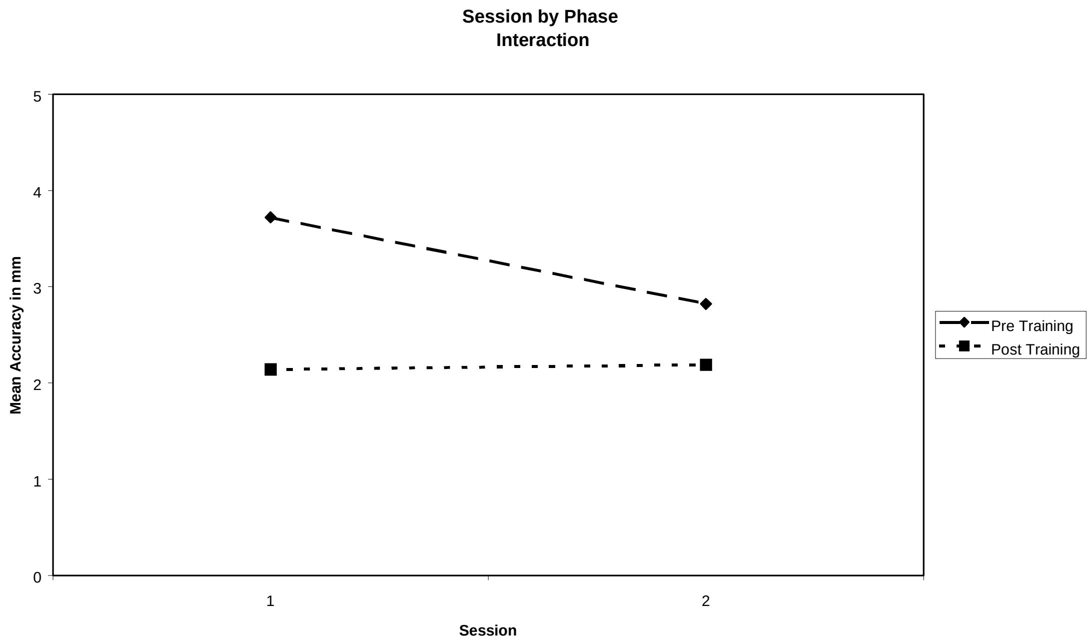


Figure 5. Session by phase of training interaction plot

Mean accuracy in mm distance from the mid point of the Judd arrows is presented for the two groups by phase of training for L pointing (Figure 6) and R pointing (Figure 7) arrows.

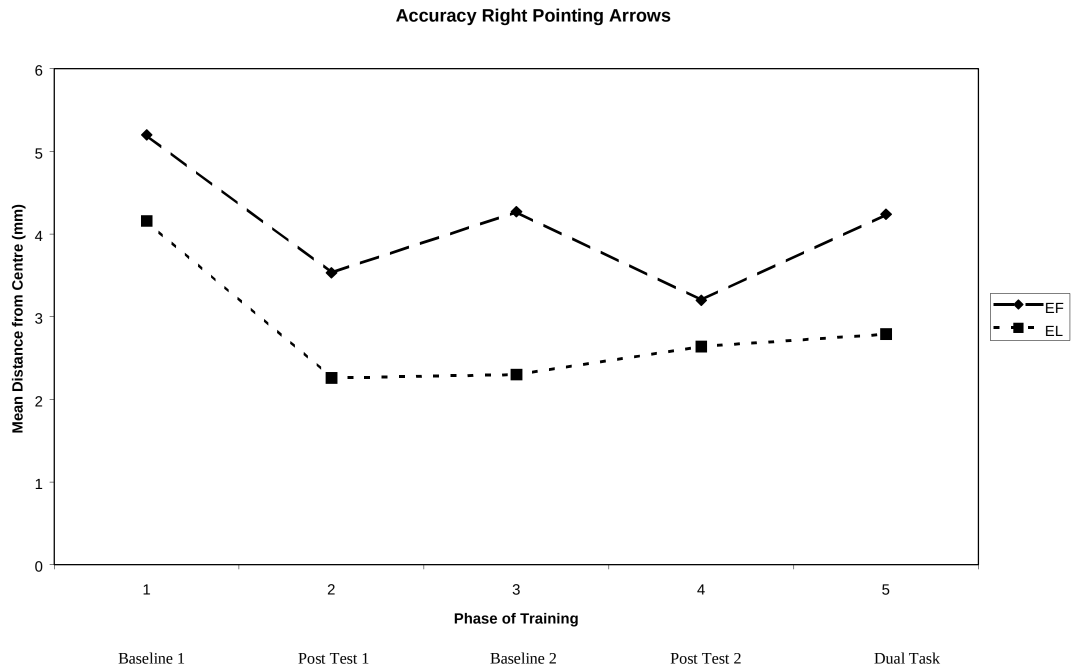


Figure 6. Accuracy for left pointing arrows

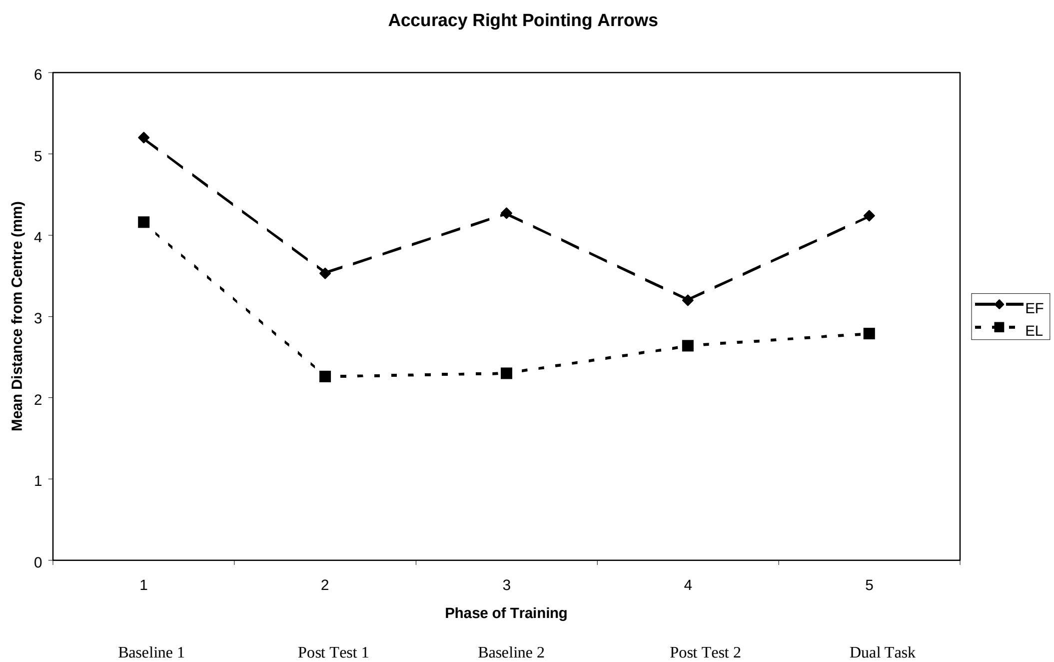


Figure 7. Accuracy for right pointing arrows

Hypothesis 3—Dual Task Accuracy

It was hypothesized that accuracy of midpoint judgements would be more resistant to the effects of increased cognitive demands under a dual task condition. A two factor, two levels per factor, repeated measures ANOVA was carried out comparing Phase of Training (post test 2 and dual task) by Arrow Direction (L, R). As with accuracy in the ANOVA for the two sessions, there were within subjects main effects for Phase of Training $F(1, 33) = 6.341$, $p < .05$ and Arrow Direction $F(1, 33) = 4.606$, $p < .05$. Both types of training showed greater accuracy in the post test 2 condition than in the dual task condition, as can be seen in the means and standard deviations in Table 6. As in the Session by Phase of Training by Arrow Direction analysis, participants were more accurate on L pointing arrows than R pointing arrows during post test 2 and the dual task. There were no interactions. The pattern of means was toward the EL group performing better in the dual task condition $F(1, 33) = 3.52$, $p = .07$, as can be seen in Figures 4 and 5 above. Power was affected by the reduced number of participants in this analysis compared with the Session by Phase of Training by Arrow Direction analysis, with observed power for the main effects of Phase at .69 compared to .99, Arrow at .55 compared to .99, and between subjects for training type (EF or EL) at .45 compared to .61.

Table 6

Accuracy During Dual Task by Arrow Direction

		Mean	Std. Error	95% Confidence Interval	
Phase of Training				Lower Bound	Upper Bound
	Post 2	2.27	0.27	1.71	2.81
	Dual Task	2.95	0.35	2.23	3.66
Arrow Direction					
	Left	1.95	0.29	1.37	2.54
	Right	3.26	0.51	2.22	4.29

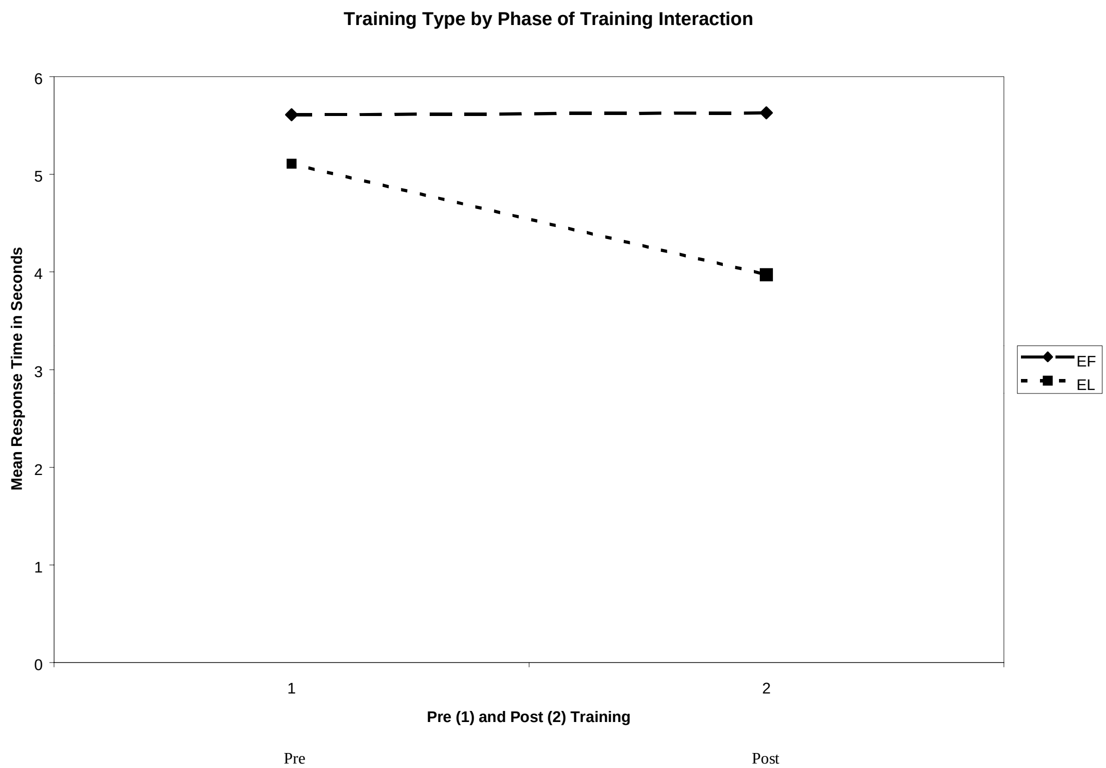
Hypothesis 4—Response Speed

Response speed was predicted to be more resistant to the effects of increased cognitive demands when training was errorless. This hypothesis was examined in two repeated measures ANOVAs. The first analysis included three factors, two levels per factor, for Session (1, 2) by Phase of Training (pre or post) by Arrow Direction (L, R). The second analysis included two factors with two levels, Phase of Training (post test 2 and dual task), by Arrow Direction (L, R). In the first analysis there was a within subjects main effect for Phase of Training $F(1, 29) = 4.56$, $p < .05$ and an interaction between Phase of Training and Type of Training $F\,(1, 29) = 4.75$, $p < .05$ shown in Figure 8. The pattern of means was toward the EL group being faster in response time $F(1,29) = 4.08$, $p = .053$. Observed power was again compromised by the reduced number of participants in this analysis with the main effect of Phase at .54, the interaction at .56, and the between subjects for training type (EF or EL) at .50. Means and standard deviations, collapsed across sessions for the within subjects main effect and collapsed across phase of training in the interaction are presented in Table 7.

Table 7

Response Speed by Phase of Training and Training Type

			Mean	Std. Error	95% Confidence Interval	
Phase of Training					Lower Bound	Upper Bound
		Pre	5.36	0.33	4.69	6.03
		Post	4.8	0.27	4.26	5.34
Training * Phase		Phase				
Training	EF	Pre	5.61	0.47	4.65	6.58
		Post	5.63	0.38	4.85	6.41
	EL	Pre	5.11	0.46	4.17	6.04
		Post	3.97	0.37	3.22	4.73



<u>Figure 8.</u> Training type by phase of training interaction plot

Mean response time is presented for the EF and EL groups by phase of training for L pointing (Figure 9) and R pointing (Figure 10) arrows.

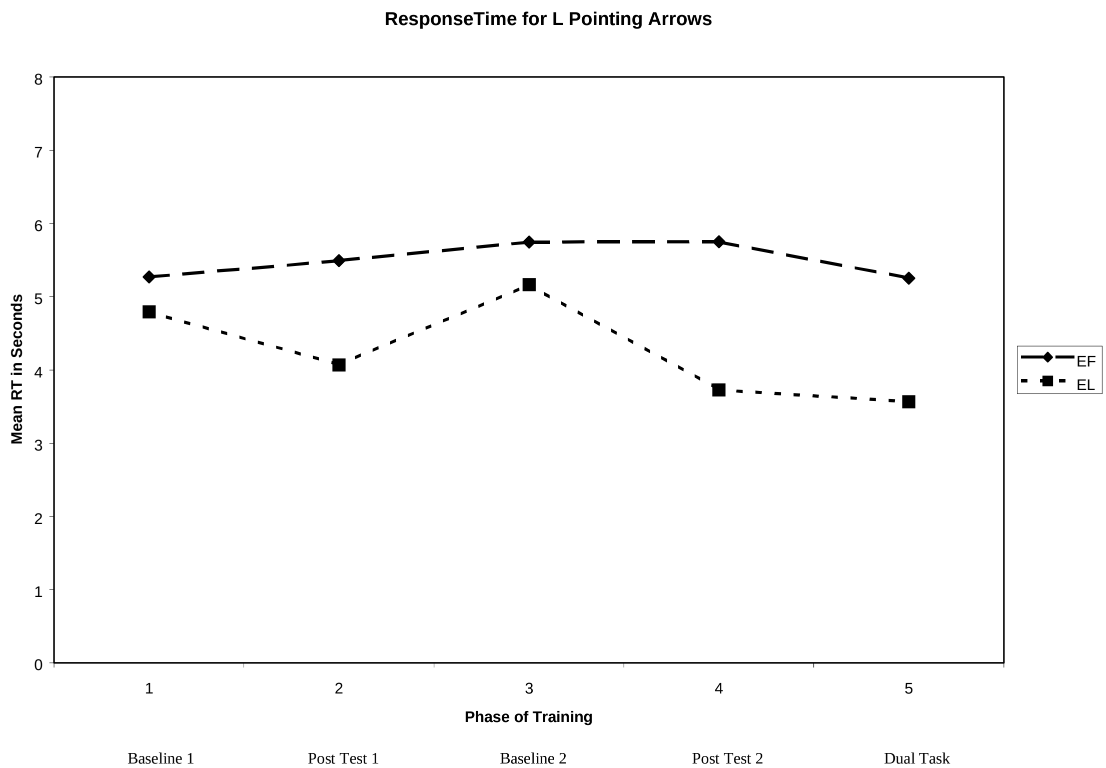


Figure 9. Response time for left pointing arrows

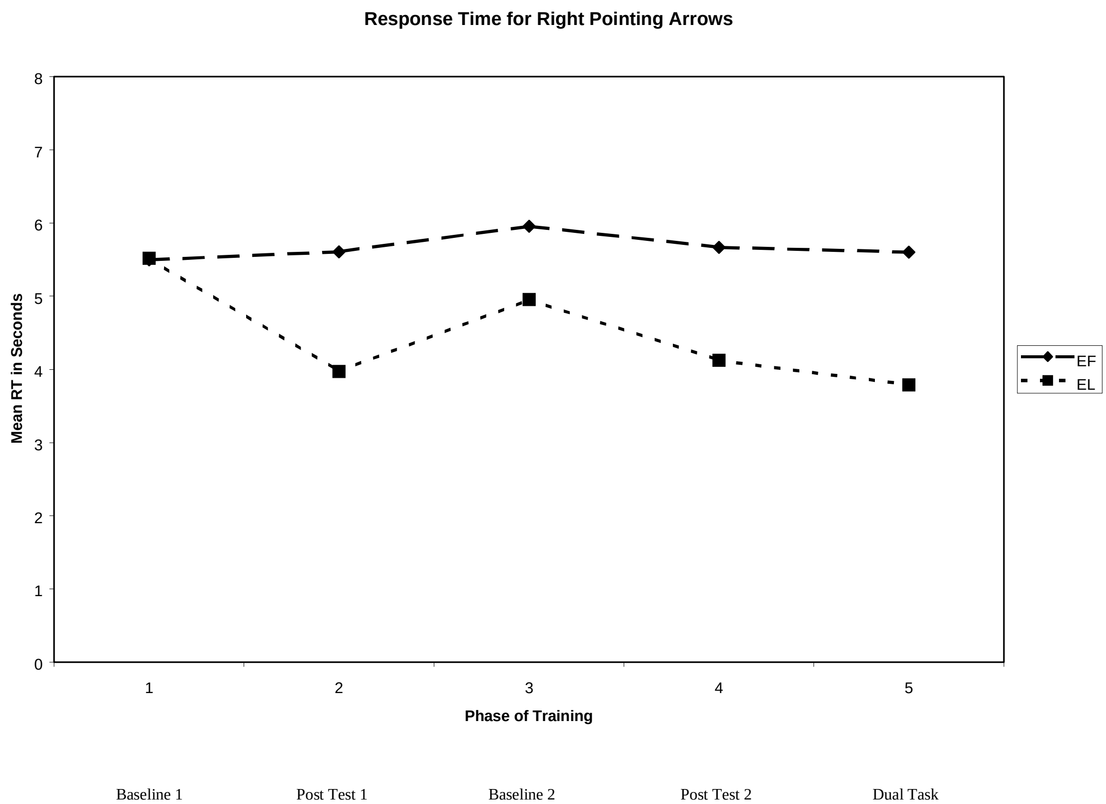


Figure 10. Response time for right pointing arrows

A two factor, two levels per factor, repeated measures ANOVA was carried out comparing Phase of Training (post test 2 and dual task) by Arrow Direction (L, R). There was a within subjects main effect for Arrow Direction $F(1, 33) = 5.51$, $p < .05$, and a between subjects effect for Type of Training $F(1, 33) = 11.37$, $p < .01$. Power was improved in this analysis to .90. Means and standard deviations, collapsed across phases for the within subjects main effect and for the between subjects effect of Type of Training, are presented in Table 8.

As can be seen in Figures 7 and 8 above, the EF group did not improve their response time as a result of training, whereas the EL group not only improved their response time but were unaffected by the dual task.

Table 8

Response Speed by Arrow Direction and Training Type

		Mean	Std. Error	95% Confidence Interval	
Arrow				Lower Bound	Upper Bound
	Left	4.55	0.28	3.97	5.12
	Right	4.78	0.29	4.20	5.36
Training	EF	5.61	0.39	4.81	6.40
	EL	3.72	0.40	2.90	4.54

Discussion

Summary of Results

The Judd Arrow illusion, as has been consistently demonstrated in prior studies, produced a reliable misperception of midpoint judgement by the participants in this study, with the exception of two individuals who were immune to the illusory effects at the beginning of both sessions. For the remainder of the participants it induced a distorted perception of space analogous to that found in unilateral neglect (Fleming & Behrmann, 1998). Both the left and right pointing arrows produced a bias toward the arrow tail, with the right arrow having a greater illusory effect. Given that the arrow tail is left of center on the right pointing arrows, this effect is most likely an enhancement of the normal perceptual bias to the left of center in plain line bisection (Milner et al., 1992; Lezak, 1995).

While it was not possible to demonstrate that errorless learning was a more efficient means of learning the perceptual motor task in this study due to methodology, it is evident that errorless learning resulted in greater accuracy under normal performance and greater speed under cognitively challenging conditions than errorful learning. The errorlessly trained individuals did not sacrifice accuracy for response speed, while those who were errorfully trained failed to improve their speed as a result of training.

It was hypothesized, by training individuals to a specific accuracy criterion over a repeated series of training trials, that the errorless group would require fewer training trials to reach that criterion. However, to guard against the possibility of some individuals not being able to reach criterion regardless of how much training they received, a discontinue rule was used. If anyone did not improve their accuracy at the end of three consecutive training trials, training was stopped. With this rule in place, no individual in either group received more than four training trials per session. Consequently very little distinction could be made between the two groups on this measure. In previous studies with errorless learning in which memory impaired individuals were trained to criterion, the tasks have typically been semantic in nature such as list learning (Parkin et al., 1998) which may be more amenable to this approach. In both the neuropsychological and learning disabilities literature criterion has often been dealt with using a “chaining” procedure in which no new information or step is introduced until the current information is mastered (Clare et al., 1999), which was not appropriate for this study. In the perceptual motor literature, more often training has consisted of a fixed number of training trials such as with Prather's (1971) pilots and Maxwell and colleague's (in press) novice golfers. The training to criterion approach was selected as a superior method for testing retention on follow up but, in the effort to protect participants from the possibility of reaching a point of diminishing returns if they failed to reach criterion, the discontinue rule was used. Use of this rule then became tantamount to a fixed number of training trials.

An alternative approach to evaluating the efficiency hypothesis was considered, the number of individuals reaching criterion in both groups at each post training phase. While more individuals in the errorless group reached criterion at each phase, there were insufficient numbers in either group for the differences to be detectable. Perhaps with a larger sample size, this particular measure would have been more sensitive to group differences. Since it was not, comparisons between those who did and those who did not reach criterion were not made.

While both groups' accuracy of midpoint judgement improved as a result of training, the errorless group out performed the errorful group at each post training phase. Given that there were no differences between the two groups on any of the demographic characteristics or measures of intelligence, memory, or attention that could account for post training performance differences; and, given that the two groups had comparable performance on the Judd Arrows at the beginning of session one, the errorless training was the more effective method. It is interesting to note that, though both groups were not as accurate at the beginning of session two as they had been at the end of session one, the second day of training did not improve their accuracy beyond what was achieved at the end of the first session. This finding could have been influenced by two aspects of the analysis. Any person who met criterion at the beginning of the second session received no additional training and this performance data was also used as their post test performance. It is conceivable that, though these individuals met criterion without training, their performance had been better than criterion at the end of the first session. Since there were only six people in this category it is more likely, with the discontinue rule operating in both sessions, that there was simply a limit to how accurate anyone would become in this training paradigm.

As expected, the introduction of a concurrent mental manipulation task during the Judd Arrow bisection produced less accurate performance for both groups. And, both groups remained significantly better on the left pointing arrows than the right during the dual task. While the hypothesis was not confirmed that the errorless group would be more accurate during the dual task, there was an observable difference toward better performance on their part, especially on the right pointing arrows. It is likely that more data than the loss of two people's in the errorless group, who were erroneously not given the dual task, would be necessary to show a significant difference between the two groups.

When it came to response speed, the errorless group definitely out performed the errorful group during the dual task. The absence of six people's response time data during the first session compromised the ability to show a difference between the two groups in the pre versus post training comparisons. Interestingly, though there were no differences between the two groups in response time before receiving any training and both groups were given identical instructions to work as quickly and accurately as they could, the errorful group failed to improve their speed at any phase during the training while the errorless group's speed continued to improve throughout.

Data collection problems were corrected prior to the second session making it possible to compare the two groups reliably on their end of session versus dual task response speed. While both groups were slower on the right pointing arrows, the errorless group's response speed was significantly better on both arrow types during their final post test and the dual task. Neither group's response time appeared to be affected by the dual task. The errorless group demonstrated the ability to maintain their response speed gains without sacrificing their accuracy gains over the errorful group.

Methodological Issues

This study made several improvements over the earlier study by Connor and colleagues (2000) leading to evident differences between the performance of individuals trained errorlessly and those allowed to make errors during learning. Unlike the earlier study in which each person had one session of each type of training, internal validity was controlled by random assignment to either the control or experimental group. Rather than receiving only one block of training trials from which there was no evident carry over to the second session, participants in both groups in this study performed better at the beginning of the second session than they did at the beginning of the first. This finding suggests that, even though training to criterion did not demonstrate one type of training to be superior to the other in efficiency, this technique did lead to retention of accuracy between sessions. As was reported by Baddeley and Wilson (1994), in their normal elderly controls, the rate of forgetting between session one and two was significantly less for material learned errorlessly than that learned errorfully. Also, in the earlier study small sample size led to no detectable differences in accuracy between the two types of training. While computer problems early in this study, along with experimenter error during the dual task, did result in missing data leading to loss of power in some of the analyses, there was sufficient information to show detectable differences between the two types of training for both accuracy and speed.

The Connor et al. (2000) study did not address the effects of cognitive challenge on the learning that took place. In the present study, while both groups lost accuracy during the dual task, the errorlessly trained group did not loose the response speed gained during training. Since the errorful group did not improve their speed as a result of training, they did not loose what had not been gained, while the errorless group's response speed gains remained unchanged during the dual task. Masters et al. (in press) attributed the lack of interference of the dual task on the errorlessly trained Parkinson's patients to their not needing to make use of the resources of working memory to execute their task. This raises the question of whether the errorless learning was implicit. While this particular study was not designed to establish which type of learning was taking place in either the errorless or errorful groups, the lack of interference by the dual task on response speed would suggest that implicit perceptual motor learning was taking place. However, since the errorful group's response speed did not get worse, though their accuracy did, this calls into questions whether both or neither type of learning was implicit in this task. One way to examine this in future studies would be to have participants explicate what rules they developed about the illusion to which they were responding. If the errorless training was implicit that group, like Maxwell et al.'s (in press) novice golfers, would be expected to generated fewer hypotheses about rules they needed to follow to perform accurately, suggesting that the learning was not declarative.

This study was not without its limitations. In addition to the loss of power as a result of missing data, certainly more participants were needed to be able to adequately examine the issue of whether more individuals in the errorless group reached training criterion than in the errorful group. Similarly, more participant data was needed to show a detectable difference between the groups on response speed during the first session of training and on accuracy during the dual task. This study also did not examine whether there was transfer of learning. It would improve the generalizability of the results if, in addition to the dual task, a transfer task were given at the end of the second session. That task might be either a novel length series of Judd arrows or a different stimulus, such as the Baldwin illusion (as cited in Chieffi, 1996) with unequal sized boxes at either end of the line. Also, the effect of learning could have been strengthened by including two or more arrow lengths during all phases of training.

Another way to examine the learning that took place would be to assess accuracy based on categorizing the arrows dichotomously as either near or far from the center of the screen where the cross cursor is positioned at the beginning of each stimulus. Those arrows farther from the cross cursor would require longer attentional focussing on the illusion and would give greater opportunity for error in the midpoint judgement. If there was a significant difference between the two groups on this measure it would reflect that more learning took place. It might be argued that the attentional focussing of the errorless group was actually more errorful during the application of force feedback (training) if in fact they were continuously trying to move the cursor in a direction other than the joystick would allow. One way to examine this would be to analyze the trajectory data during each baseline and the post tests for variability of movement from the true straight line path to the midpoint. If the errorless group was less variable in their trajectories as a result of training, it would counter the continuously errorful attention argument.

Implications and Future Directions

This investigation was designed as a normative study for the British Stroke Association funded research project: Cognitive Rehabilitation Using Response Guided Errorless Learning with Stroke Patients. The questions to be answered in that study concerning the rehabilitation of specific cognitive deficits are:

(1) Is errorless learning effective in remediating post-stroke deficits in attention and executive/motor functions?

(2) Is active force field technology effective in producing errorless learning?

(3) Is there retention of learning over time?

(4) Will improvement in cognitive functioning affect measures of perceived quality of life?

As our sample were normal elderly, there were no specific attentional or executive function deficits, hence the use of a visual illusion to simulate the type of attentional deficits found in stroke patients with unilateral spatial neglect. The results indicate that while both the errorful and errorless groups benefited from training to improve their accuracy, the errorless group's performance at the end of both training sessions was significantly better. From these results we can anticipate that errorless training will prove to be the superior method in remediating attentional and executive function deficits in stroke patients. It is also evident from this study that errorless training was effectively delivered using active force field technology. This group of normal elderly responded favorably to the use of the AFF equipment. Their performance for both accuracy and response speed revealed significantly better results on the part of the errorlessly (AFF) trained group. Retention of learning definitely occurred between the two training sessions with both groups performing more accurately at the beginning of the second session than at the beginning of the first, however, again the errorlessly trained group's performance was significantly better. It was inappropriate to examine quality of life measures with the normal elderly in this study so the fourth question in the stroke grant study has not been addressed. Overall, the results of the present study suggest that errorless learning using AFF for response guidance will prove to be the superior method of cognitive rehabilitation training in the stroke study.

While the stroke study did not identify response speed as a question to be answered, speed of response measures are being recorded throughout. An important finding from this study is that the errorlessly trained individuals were able to increase their response speed while the errorfully trained ones were not. Just as important, this increase was maintained without loosing their accuracy gains over the errorful group. This would suggest that using response guidance would have practical application in teaching other tasks that require perceptual motor movements, and potentially with a wider participant pool than stroke patients or the elderly. For example, in physical rehabilitation the use of force feedback for guiding motor retraining after stroke or other types of brain injury could improve the accuracy of movements to targets, while also increasing the speed at which these responses are made. This becomes particularly important in retraining hemiparetic extremities as patients often become frustrated with how long it takes to use the impaired limb and resort to the unimpaired one. This choice then cycles into a pattern of disuse that makes it more difficult, if not impossible, to use the hemiparetic extremity.

There are other applications for example with the population targeted in the early errorless learning work, those with profound learning disabilities, or with compromised physical capacity such a cerebral palsy. In both groups, incoordination is often a seriously limiting factor. If perceptual motor training can be implemented with response guidance, a pattern of smoother motor movements can be developed that could lead to less care needs on the part of the patient. Particularly for individuals with severe spastic tone the forces applied with the AFF joystick would make it possible for the user to not be able to override the system. During manual response guidance by physical therapists, a patient's spastic tone, or the dead weight of a densely hemiparetic extremity, can override the therapist's best efforts to keep the patient's movements on course.

With the current AFF technology, it is reasonable to think of applying response guidance to computerized self-directed learning by school aged children who are either rehearsing manual responses to stimuli on the screen, or learning to make fine motor discriminations. Use of this technology can be expanded by providing exoskeletal supports on the joystick to make three dimensional movements possible. With this addition, virtual environments can be integrated into the learning process. Virtual environments would make it possible for certain perceptual motor activities to be learned and rehearsed in a simulated setting with more generalizability to the natural environment. Overall, response guided errorless learning would seem to open a wide array of applications and potential uses by unimpaired individuals as well as those with physical and cognitive limitations.

APPENDIX A

Participant Identification Number for this trial:

CONSENT FORM

Title of Project: Using a computer to aid learning

Names of Researchers:

Prof Alan Wing	0121 414 7954
Dr Martyn Bracewell	0121 472 1311
Bonnie Connor, MEd	0121 414 4910

Please initial each point below

1. I confirm that I have read and understand the information sheet dated ______________________ for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.

3. I agree to take part in the above study.

Name: (signed) ____

Name: (blocked capitals) ________________________________

Project Coordinator: Bonnie Connor, MEd

Project Coordinator's Signature: ___________________________________

Date: ______________________

APPENDIX B

INFORMATION SHEET

Title: Using a computer to aid learning

INVITATION:

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

1. What is the purpose of the study?

We want to find out if using a computer aids in learning more quickly by guiding participants to the correct response. This study will use a computer and a joystick.

2. Do I have to take part?

It is up to you to decide whether or not to take part. You will be asked to sign a Consent Form and will be given a copy to keep. If you decide to take part you are still free to withdraw at any time and without giving a reason. If you withdraw before the end of the study all information collected about you will be destroyed.

3. What will I have to do?

You will then be asked to attend the University of Birmingham School of Psychology. If you agree to take part, you will be given some tests and questions to answer about yourself and how you feel at the beginning. Some of the questions may be personal. You will be asked to take some brief tests of memory, attention/concentration, and general capabilities. The time needed to complete the tests is likely to be less than 1 hour. You may refuse to answer some or all of the questions.

You will be asked to attend two sessions, each session lasting about one and one-half hours and the second session lasting about one hour. You will be paid £15 for your participation at the conclusion of your second and final session.

4. What is the procedure being tested?

The procedure is using a computer and joystick to find out if this helps individuals to learn more quickly.

5. What are the benefits?

The information we get from this study may help us to develop better learning techniques in the future.

6. What are the risks?

There are no known risks or side effects from using the joystick and the computer tasks.

7. What if something goes wrong?

If you have any questions, or if in the unlikely event that problems arise in connection with taking part in this study, you should contact the project co-ordinator, Bonnie Connor at 0121 414 4910 or the secretary of the Psychology Department Ethics Committee, Dorothy Trinder at 0121 414 4932.

8. Will my taking part in this study be kept confidential?

All information collected about you during the course of the research will be kept strictly confidential. Your name will not appear on any of the testing or questions. Your full name will appear only on the Consent Form that will be kept in a separate file from all other information about you. You will not be identified in the analysis of data, or in the publication of the results. Your information will be released only with your written consent. If you withdraw before the end of the study all information collected about you will be destroyed.

9. What will happen to the results of the research study?

When the research is complete, information about the general results will be available to you or any other interested persons, upon request. The results of this research may appear in scientific publications without identifying you by name.

10. Who has reviewed the study?

This study has been reviewed and approved by the University of Birmingham School of Psychology Research Ethics Committee and the University of North Texas Institutional Review Board, phone: (940) 565-3940.

11. Contact for Further Information

You should contact the project coordinator, Bonnie Connor, at 0121 414 4910 or any of the project investigators listed below:

Prof Alan Wing	0121 414 7954
Dr Martyn Bracewell	0121 472 1311

THANK YOU FOR TAKING PART IN THIS STUDY

APPENDIX C

Using A Computer to Aid Learning

Name: ______________________

Please answer the following questions:

1.	Male/Female	
2.	If female, are you currently taking oestrogen (hormone) replacement therapy?	Yes/No
3.	Right handed/left handed	______
4.	Age	______
5.	At what age did you leave the education system?	
6.	Is your first language English?	Yes/No
7.	Have you ever had brain damage of any kind?	Yes/No
8.	Do you have any history of alcohol or other substance abuse?	Yes/No
9.	Do you have any prior history of psychiatric illness?	Yes/No
10.	Do you have any visual impairment that would keep you from seeing objects on a computer screen?	Yes/No
11.	Do you have any hearing impairment that would keep you from hearing computer generated tones?	Yes/No

APPENDIX D

Mood Assessment Scale

1.	Are you basically satisfied with your life?	Yes/No
2.	Have you dropped many of your activities and interests?	Yes/No
3.	Do you feel that your life is empty?	Yes/No
4.	Do you often get bored?	Yes/No
5.	Are you hopeful about the future?	Yes/No
6.	Are you bothered by thoughts that you can't get out of your head?	Yes/No
7.	Are you in good spirits most of the time?	Yes/No
8.	Are you afraid that something bad is going to happen to you?	Yes/No
9.	Do you feel happy most of the time?	Yes/No
10.	Do you often feel helpless?	Yes/No
11.	Do you often get restless and fidgety?	Yes/No
12.	Do you prefer to stay home rather than go out and doing new things?	Yes/No
13.	Do you frequently worry about the future?	Yes/No
14.	Do you feel you have more problems with memory than most?	Yes/No
15.	Do you think it is wonderful to be alive now?	Yes/No
16.	Do you often feel downhearted and blue?	Yes/No
17.	Do you feel pretty worthless the way you are now?	Yes/No
18.	Do you worry a lot about the past?	Yes/No
19.	Do you find life very exciting?	Yes/No
20.	Is it hard for you to get started on new projects?	Yes/No
21.	Do you feel full of energy?	Yes/No
22.	Do you feel that your situation is hopeless?	Yes/No
23.	Do you think that most people are better off than you are?	Yes/No
24.	Do you frequently get upset about little things?	Yes/No
25.	Do you frequently feel like crying?	Yes/No
26.	Do you have trouble concentrating?	Yes/No
27.	Do you enjoy getting up in the morning?	Yes/No
28.	Do you prefer to avoid social gatherings?	Yes/No
29.	Is it easy for you to make decisions?	Yes/No
30.	Is your mind as clear as it used to be?	Yes/No

APPENDIX E

Short 2-Axis Stick | **WITTENSTEIN aktiv technologies limited**

Reconfigurable Active Control Sticks

Wittenstein Aktiv Technologies Limited have developed a range of control sticks that provide programmable feel characteristics using force feedback. Their high performance and programmability make them suitable for both reconfigurable and high fidelity controllers. They have a wide range of applications.

- active sticks, throttles and rudders for aircraft helicopters, simulators and trainers;
- remote control of forces applied via tele-operated robots or manipulators;
- drive-by-wire control.

They are extremely compact and easy to install. Integration is simplified by the use of CANbus serial bus technology to couple twin sticks and link multiple sticks to a stick control module.

The product described in this leaflet is a two-axis side-arm or centre stick controller that has been developed primarily for aircraft and helicopter simulator and trainer applications.

Unique Features

The Wittenstein two axis side-arm and centre stick has the following unique features:

- both compact and light;
- smooth, precise and repeatable feel;
- incorporates proven Wittenstein motors, gearboxes and motor controllers;
- mechanically simple and easy to mount;
- robust and reliable;
- latest integrated digital motor control technology;
- CANbus to link sticks to a compact stick control module.

Wittenstein Aktiv Technologies

Wittenstein Aktiv Technologies Limited specialises in the application of active force-feel technology. They have the advantage of having all the technology in-house. This enables them to react quickly to market needs as they can take standard products and adapt them to the needs of the application. Wittenstein's many years of experience as a supplier of gearboxes, ac brushless motors including integrated motor-gearboxes as well as motor controllers provides them with a unique experience in the field of electric drive systems. This know-how has been incorporated into their active stick products.

Operation Of The System

High dynamic performance brushless ac motors are used to drive the pitch and roll axes of the stick through two stage planetary precision gearboxes. Each motor has a digital motor controller integrated in the stick enclosure that determines the torque, speed and position of the associated axis. Force transducers mounted on the stick, feed the force signals back to the stick control module. This enables a force-feel characteristic to be achieved at the grip that can be reconfigured or dynamically changed to simulate different systems, or changing operating conditions. For simpler systems alternate control algorithms can be used to allow the force transducer to be dispensed with.

The unique mechanical design of the unit that is both compact and very light has been achieved by using the low backlash low friction integrated motor-gearboxes developed by Wittenstein Motion Control GmbH for applications such as robotics and manipulators.

A separate stick control module is used to control the sticks. For multiple stick and throttle applications, units can be linked to one control module using a 6 core power and CANbus cable for both implementing and co-ordinating control.

Technical Data:

STICK SERVO UNIT

Travel:

- ±18° in each axis

Force Capability:

- continuous torque 274lb.in (31Nm);
- peak torque 510lb.in (62Nm);

equivalent to a force at 6.4″ (153mm) pivot radius of:

- 43lb. (202N) continuous;
- 86lb. (404N) peak.

Size:

- 10.67″ (271mm) × 4.18″ (106.5mm) × 4.88″ (124mm), L,H,W.

Dynamically Variable Characteristics:

- force-feel curve;
- hard and soft stops;
- trimming and trim release;
- centring features and special cues;
- stick shaker;
- model parameters bandwidth, damping, friction.

Maximum Bandwidth

- > 6Hz at 0.45 lb./degree (2.0 N/degree) force-feel stiffness.

STICK CONTROL MODULE

Features:

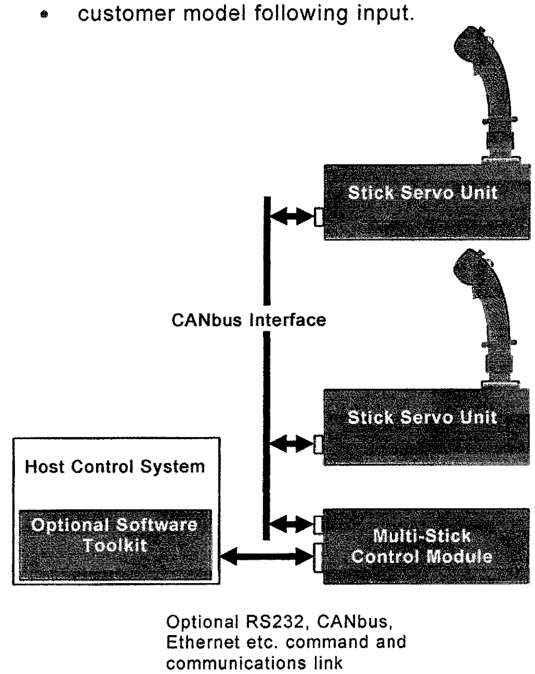
- multiple stick control capability;
- CANbus interface to stick servo units;
- Ethernet, RS232 or customised interfaces to host;
- analogue outputs of stick parameters.

Size:

- 5.24″ (133mm) × 8.39″ (213mm) × 10.47″ (266mm) H,W,D.

Customer Options for:

- characteristics defined in configuration file;
- software toolkit for setting defaults and system evaluation.
- customer model following input.



Wittenstein Aktiv Technologies Limited, 3b, Osprey Court, Hawkfield Way, Bristol, BS14 0BB, UK.
Tel: +44 (0) 117 964 0327, fax +44 (0) 117 964 0397, email info@wittenstein.co.uk

APPENDIX F

JUDD ARROW EXPERIMENT INSTRUCTIONS (EF)

Practice: "A series of horizontal lines are going to be presented on the computer screen. Your task is to move the black cross to the midpoint of the horizontal line using the joystick. Press and release the button on the top of the joystick to bring up each new line. Use the joystick to move the cross all the way to the midpoint of the horizontal line, then press and release the button to mark the midpoint. Do not worry, however, about lining up the horizontal line of the cross exactly with the horizontal line you are bisecting. Wait until the stick has returned the cross to the middle of the screen before pressing the button to bring up a new line. The stick is sensitive so be careful that you do not let the stick move off the target when pressing the button. To review, there are 2 button presses for each trial—one to bring up the line and one to mark your judgement of its midpoint. First we will try a few for practice. Do you have any questions?" (*give 5 and if more are necessary continue practice until individual follows sequence correctly for 3 consecutive trials*).

Pre-test: "Now we are ready to begin. Work as quickly and as accurately as you can. Do you have any questions?" (*10 horizontal line presentations*)

Baseline: "A series of horizontal arrows are now going to be presented on the computer screen. Again your task is to move the black cross to the midpoint of the horizontal line of the arrow using the joystick. Continue to press and release the button on the top of the joystick to bring up each new arrow. Use the joystick to move the cross to the midpoint of the horizontal line of the arrow, then press and release the button to mark the midpoint. Wait until the stick has returned the cross to the middle of the screen before pressing the button to bring up a new arrow. So again, there are 2 button presses for each trial—one to bring up the arrow and one to mark your judgement of its midpoint. Work as quickly and as accurately as you can. Do you have any questions?" (*10 arrow presentations*)

Training: "You will now be receiving auditory feedback each time you bisect an arrow. There is a pleasant tone sound when you bisect the horizontal line in the middle, it sounds like this (*give tone*) and a cluncking tone that sounds like this (*give tone*) when you miss. Work as quickly and as accurately as you can. Do you have any questions?" (*16 arrow presentations*)

Post-Test: "You will now no longer receive auditory feedback. Continue to work as quickly and as accurately as you can. Do you have any questions?" (*16 arrow presentations*)

Training to Criterion: *Training will continue in each of the two sessions until the participant reaches the target criterion in a block of post-test trials. The criterion is based on the individual participant's mean midpoint judgement and standard deviation on the 10 horizontal lines in the pre-test condition. Criterion is set at a z score of 1.15 such that 75% of the post-test arrow bisections will be within the individual's pre-test* *standard deviation of their mean midpoint judgement on the horizontal lines. Participants will be given a rest between each block of training trials until criterion is reached. If criterion is not reached in a single session, training for that session will be discontinued after the individual fails to show improvement in z score for 3 consecutive blocks of training trials.*

***Post-Test Dual Task/Session 2:** *Once criterion has been reached in the second session, a final block of 16 arrows will be presented with these instructions:* **"**Before you proceed I would like for you to say some numbers and letters out loud. I want you to pair each number with its corresponding letter in the alphabet beginning with number 1 and letter A. So for example, begin with 1 A, followed by 2 B, 3 C, and so on. Now you begin with 3 C and say the sequence out loud." (*Stop on 6 F*). "OK, now while you do the final series of arrow bisections I want you to say the number/letter sequence in your head. Periodically I will ask you to tell me what sequence you are on. The arrow bisection task remains the same, except now you will no longer receive auditory feedback. Continue to work as quickly and as accurately as you can. Do you have any questions?"

APPENDIX G

JUDD ARROW EXPERIMENT INSTRUCTIONS (EL)

Practice: "A series of horizontal lines are going to be presented on the computer screen. Your task is to move the black cross to the midpoint of the horizontal line using the joystick. Press and release the button on the top of the joystick to bring up each new line. Use the joystick to move the cross all the way to the midpoint of the horizontal line, then press and release the button to mark the midpoint. Do not worry, however, about lining up the horizontal line of the cross exactly with the horizontal line you are bisecting. Wait until the stick has returned the cross to the middle of the screen before pressing the button to bring up a new line. The stick is sensitive so be careful that you do not let the stick move off the target when pressing the button. To review, there are 2 button presses for each trial—one to bring up the line and one to mark your judgement of its midpoint. First we will try a few for practice. Do you have any questions?" (*give <u>5</u> and if more are necessary continue practice until individual follows sequence correctly for <u>3</u> consecutive trials*).

Pre-test: "Now we are ready to begin. <u>Work as quickly and as accurately as you can</u>. Do you have any questions?" (*<u>10</u> horizontal line presentations*)

Baseline: "A series of horizontal arrows are now going to be presented on the computer screen. Again your task is to move the black cross to the midpoint of the <u>horizontal line</u> of the arrow using the joystick. Continue to press and release the button on the top of the joystick to bring up each new arrow. Use the joystick to move the cross to the midpoint of the horizontal line of the arrow, then press and release the button to mark the midpoint. Wait until the stick has returned the cross to the middle of the screen before pressing the button to bring up a new arrow. So again, there are 2 button presses for each trial—one to bring up the arrow and one to mark your judgement of its midpoint. <u>Work as quickly and as accurately as you can</u>. Do you have any questions?" (*<u>10</u> arrow presentations*)

Training: "You will now be receiving auditory feedback each time you bisect an arrow. There is a pleasant tone sound when you bisect the horizontal line in the middle, it sounds like this (*give tone*) and a cluncking tone that sounds like this (*give tone*) when you miss. The stick will also assist you to find the midpoint. <u>Work as quickly and as accurately as you can</u>. Do you have any questions?" (*<u>16</u> arrow presentations*)

Post-Test: "You will now no longer receive auditory feedback or assistance from the stick. <u>Continue to work as quickly and as accurately as you can</u>. Do you have any questions?" (*<u>16</u> arrow presentations*)

Training to Criterion: *Training will continue in each of the two sessions until the participant reaches the target criterion in a block of post-training trials. The criterion is based on the individual participant's mean midpoint judgement and standard deviation on the 10 horizontal lines in the pre-test condition. Criterion is set at a z score of 1.15 such that 75% of the post-training arrow bisections will be within the individual's pre-*

test standard deviation of their mean midpoint judgement on the horizontal lines. Participants will be given a rest between each block of training trials until criterion is reached. If criterion is not reached in a single session, training for that session will be discontinued after the individual fails to show improvement in z score for 3 consecutive blocks of training trials.

***Post-Test Dual Task/Session 2:** *Once criterion has been reached in the second session, a final block of 16 arrows will be presented with these instructions:* **"**Before you proceed I would like for you to say some numbers and letters out loud. I want you to pair each number with its corresponding letter in the alphabet beginning with number 1 and letter A. So for example, begin with 1 A, followed by 2 B, 3 C, and so on. Now you begin with 3 C and say the sequence out loud." (*Stop on 6 F*). "OK, now while you do the final series of arrow bisections I want you to say the number/letter sequence in your head. Periodically I will ask you to tell me what sequence you are on. The arrow bisection task remains the same, except now you will no longer receive auditory feedback or assistance from the stick. Continue to work as quickly and as accurately as you can. Do you have any questions?"

APPENDIX H

Modified Trails B
(Secondary Task)

1	A
2	B
3	C
4	D
5	E
6	F
7	G
8	H
9	I
10	J
11	K
12	L
13	M
14	N
15	O
16	P
17	Q
18	R
19	S
20	T
21	U
22	V
23	W
24	X
25	Y
26	Z

APPENDIX I

No.	**Train Type**	**Sex**	**Age**	**ERT**	**Hand**	**Educ**	**zIntell**	zNART	zBD	**zMem**	zVR I	zVR II	**zAttn**	zDSp	zDSy	zTrailA	zTrailB	**Depress**
1	EF	M	68	No	R	9	1.27	0.53	2.00	1.51	1.76	1.26	0.87	0.00	1.00	1.66	0.84	No
2	EF	F	67	No	R	11	1.60	0.87	2.33	1.26	1.62	0.91	0.53	0.67	0.67	0.00	0.24	No
3	EF	M	71	No	R	19	1.03	1.40	0.67	2.19	2.16	2.23	0.84	0.67	1.33	0.82	0.55	No
4	EF	F	73	No	R	10	0.97	1.60	0.33	0.89	1.48	0.30	1.12	3.00	1.00	-0.18	0.67	No
6	EF	F	77	No	R	9	-0.67	-0.67	-0.67	-1.17	-1.00	-1.33	-2.35	-0.67	-1.33	-2.55	-3.00	Yes
7	EF	F	70	No	L	10	0.83	1.33	0.33	2.38	2.16	2.59	1.06	0.67	1.67	1.29	0.63	No
10	EF	M	70	No	R	20	1.40	1.47	1.33	1.72	2.30	1.14	1.04	0.67	1.67	1.02	0.80	No
11	EF	F	61	Yes	R	10	0.23	0.80	-0.33	1.48	2.12	0.83	-0.52	0.33	0.00	-2.03	-0.38	No
12	EF	F	67	No	R	10	-0.47	-0.60	-0.33	0.42	0.63	0.20	-1.76	-1.00	-1.33	-1.70	-3.00	Yes
13	EF	F	70	No	R	10	1.90	0.80	3.00	2.63	2.30	2.95	0.74	-0.33	1.33	1.22	0.73	No
14	EF	M	69	No	R	14	1.10	0.53	1.67	0.76	1.90	-0.39	0.38	1.00	0.00	0.67	-0.15	No
15	EF	F	75	No	R	12	1.90	1.80	2.00	2.00	2.67	1.33	0.43	0.00	0.33	0.96	0.43	No
17	EF	M	65	No	R	10	-0.94	-1.27	0.67	-0.27	0.21	-0.74	-0.54	-1.00	0.00	-0.52	-0.67	No
19	EF	F	65	No	L	10	0.76	1.20	0.33	0.25	0.77	-0.27	1.10	0.67	1.67	1.41	0.68	No
22	EF	M	70	No	R	11	0.53	0.73	0.33	2.43	2.02	2.83	0.11	-0.33	0.67	-0.18	0.30	No
23	EF	F	69	No	R	17	1.60	1.87	1.33	1.53	1.34	1.73	-0.34	-0.33	0.33	-0.69	-0.70	No
25	EF	M	67	No	L	10	1.67	0.33	2.00	0.88	1.20	0.55	0.54	-0.33	2.00	1.16	-0.67	No
26	EF	F	60	No	R	11	1.10	1.20	1.00	2.17	2.31	2.03	0.36	-0.67	0.67	0.49	0.94	No
27	EF	F	65	No	R	16	0.97	1.60	0.33	1.32	1.62	1.02	0.06	0.67	1.00	-0.85	-0.59	No
28	EF	F	76	No	R	11	1.00	1.00	1.00	0.33	0.00	0.33	1.03	1.33	1.67	0.12	1.00	No
30	EF	M	70	No	R	11	0.17	0.33	0.00	1.55	1.48	1.63	-0.79	0.33	-0.33	-1.45	-1.73	No
31	EF	F	66	Yes	R	10	0.73	1.13	0.33	0.62	1.05	0.20	0.35	0.67	1.00	-0.10	0.15	Yes
32	EF	F	60	No	R	10	0.90	0.47	1.33	2.17	2.31	2.03	0.70	-1.33	1.67	1.24	1.23	No
33	EL	M	66	No	R	10	0.50	0.00	1.00	1.20	1.62	0.79	0.23	0.00	0.33	0.60	0.00	No
34	EL	F	60	No	R	11	1.00	0.67	1.33	0.67	0.00	1.33	1.25	0.00	2.33	1.66	0.99	No
35	EL	F	63	No	R	16	1.80	1.60	2.00	2.24	2.31	2.17	0.74	0.33	1.00	0.40	1.23	No
38	EL	F	67	No	R	13	1.57	1.80	1.33	1.60	1.48	1.73	0.23	0.33	1.33	-0.94	0.21	No
39	EL	F	64	No	R	10	0.90	0.47	1.33	0.72	1.35	0.08	0.00	0.33	-0.33	-0.22	0.00	No
40	EL	F	64	No	R	11	0.74	0.47	1.00	-0.35	0.19	-0.89	0.62	0.33	0.33	0.91	0.91	Yes
41	EL	F	69	No	L	9	0.60	0.20	1.00	1.22	1.06	1.38	0.40	0.00	1.00	0.74	-0.15	No
42	EL	M	63	No	R	16	2.03	1.06	3.00	1.61	2.30	0.92	0.24	1.67	-0.33	0.07	0.99	No
43	EL	M	64	No	R	16	1.27	1.20	1.33	0.57	0.77	0.36	0.04	-0.33	0.33	0.15	0.00	Yes
44	EL	M	61	No	R	10	1.33	1.00	1.67	1.94	2.12	1.75	-0.13	1.00	0.00	-1.87	0.34	No
45	EL	M	70	No	R	16	1.80	1.60	2.00	1.84	2.30	1.48	1.52	3.00	2.00	0.49	0.57	No
46	EL	F	64	No	R	12	1.20	0.73	1.67	1.87	2.12	1.61	0.75	1.00	0.67	0.49	0.84	No
47	EL	F	60	Yes	R	16	1.50	1.33	1.67	1.74	1.73	1.75	0.35	-0.33	1.00	0.24	0.50	No
49	EL	M	67	No	R	10	0.50	0.00	1.00	0.44	0.92	-0.04	-0.03	-0.67	0.33	0.24	-0.02	No
51	EL	F	60	No	R	11	1.05	1.10	1.00	0.38	1.50	0.75	0.80	1.33	0.67	0.74	0.47	No
53	EL	M	70	No	R	22	1.07	1.80	0.33	1.93	1.62	2.23	0.15	0.67	1.33	-1.11	-0.30	No
54	EL	M	76	No	R	9	0.24	-0.53	1.00	1.00	1.67	0.33	0.02	-0.67	0.33	0.46	-0.05	No
55	EL	F	71	No	R	9	-1.00	-1.00	-1.00	-0.29	0.93	-1.50	-1.99	-1.00	0.00	-1.98	-3.00	Yes
58	EL	F	68	No	R	10	-1.10	-0.53	-1.67	-1.31	-1.06	-1.56	-1.35	-0.33	-1.00	-2.54	-1.53	Yes
60	EL	F	63	No	R	16	1.77	1.87	1.67	1.54	2.30	0.78	1.27	0.67	1.67	1.50	1.23	No

APPENDIX J

The WAIS-R Full Scale, Verbal and Performance IQs predicted from the number of errors made on the NART

NART Errors	Predicted Full Scale IQ	Predicted Verbal IQ	Predicted Performance IQ
0	131	127	*128
1	129	126	127
2	128	125	126
3	127	124	125
4	126	123	123
5	124	122	122
6	123	121	121
7	122	119	120
8	121	118	119
9	120	117	118
10	118	116	117
11	117	115	116
12	116	114	115
13	115	113	114
14	113	111	112
15	112	110	111
16	111	109	110
17	110	108	109
18	108	107	108
19	107	106	107
20	106	105	106
21	105	103	105
22	103	102	104
23	102	101	102
24	101	100	101

NART Errors	Predicted Full Scale IQ	Predicted Verbal IQ	Predicted Performanc e IQ
25	100	99	100
26	98	98	99
27	97	97	98
28	96	95	97
29	95	94	96
30	94	93	95
31	92	92	94
32	91	91	93
33	90	90	91
34	89	89	90
35	87	87	89
36	86	86	88
37	85	85	87
38	84	84	86
39	82	83	85
40	81	82	84
41	80	81	83
42	79	80	82
43	77	78	80
44	76	77	79
45	75	76	78
46	74	75	77
47	73	74	76
38	71	73	75
49	70	72	74
50	69	70	73

WAIS-R: MEAN = 100
Standard Deviation = 15

Ref. Nelson & Willison (1991).

Geriatric Depression Scale (Mood Assessment Scale)

Subjects	N	M	SD
Mild depression	26	15.05	4.34
Severe depression	34	22.85	5.07
Controls	40	5.75	4.34
	>8	>10	>13
Sensitivity	90	84	80
Specificity	80	95	100

Normal = 0-9; mild = 10-19; severe = 20-30

Ref. Spreen & Strauss (1998)

Means and SDs for Adults on the Trail Making Test

		Trails A		Trails B	
Age	N	M	(SD)	M	(SD)
60-69	61	35.8	(11.9)	81.2	(38.5)
70-74	30	41.3	(15.0)	111.4	(72.2)
75-79	31	47.2	(17.0)	119.4	(50.2)
80-85	28	60.7	(26.0)	152.2	(80.1)

*Extrapolated from Yeudall et al. (1987) and Tombaugh et al. (1996)

Ref. Spreen & Strauss (1998)

Means and Standard Deviations of Raw Scores on Subtests by Age, for the Standardization Sample

	Age Group					
	55-64 (N=54)		65-69 (N=55)		70-74 (N=30)	
Subtest	M	SD	M	SD	M	SD
Visual Reproduction I	29.0	3.2	26.5	7.1	24.2	7.3
Visual Reproduction II	25.4	7.2	21.3	8.5	16.5	8.3

Note: Means and standard deviations are in unweighted raw score units.

Ref: WMS-R Manual (1981)

MOANS Scaled Scores. Midopint Age = 76 (Age Range = 71-81, *n* = 160)

WMS-R Subtests—Immediate Recall Measures

MOANS Scales Scores	X Visual Reprod. I
2	0-13
3	14-15
4	16
5	17-18
6	19-29
7	21-22
8	23-24
9	25-26
10	27-29
11	30-32
12	33
13	34
14	35
15	36
16	37
17	38
18	39-41

MOANS Scaled Scores. Midopint Age = 76 (Age Range = 71-81, *n* = 160)

	WMS-R Subtests—Delayed Recall Measures
MOANS Scales Scores	X Visual Reprod. I
2	0-1
3	2-3
4	4
5	5-6
6	7-9
7	10-11
8	12-15
9	16-17
10	18-20
11	21-24
12	25-28
13	29-31
14	32-33
15	34-35
16	36
17	37-39
18	40-41

Note: MOANS = Mayo's Older Americans Normative Studies. WMS-R = Wechsler Memory Scale—Revised. MOANS scaled scores are corrected for age influenced.

Ref. Spreen & Strauss (1998)

Scales Scores Equivalents of Raw Scores—Ages 55-64

Verbal		Performance	
Scaled Score	Digit Span	Block Design	Scaled Score
19	26-28	48-51	19
18	25	45-47	18
17	24	43-44	17
16	23	41-42	16
15	22	39-40	15
14	20-21	36-38	14
13	18-19	32-35	13
12	17	27-31	12
11	15-16	24-26	11
10	14	22-23	10
9	13	19-21	9
8	11-12	16-18	8
7	10	11-15	7
6	9	8-10	6
5	8	4-7	5
4	6-7	2-3	4
3	3-5	1	3
2	1-2	0	2
1	0	-	1

Ref. WAIS-R Manual (1981)

Scales Scores Equivalents of Raw Scores—Ages 65-69

Verbal		Performance	
Scaled Score	Digit Span	Block Design	Digit Symbol
19	25-28	47-51	78-93
18	24	44-46	72-77
17	23	41-43	66-71
16	22	38-40	62-65
15	21	35-37	57-61
14	19-20	32-34	52-56
13	18	30-31	48-51
12	16-17	26-29	44-47
11	14-15	22-25	40-43
10	13	19-21	36-39
9	12	16-18	32-35
8	10-11	11-15	27-31
7	9	7-10	21-26
6	8	3-6	15-20
5	7	2	10-14
4	6	1	7-9
3	3-5	0	5-6
2	1-2	-	3-4
1	0	-	0-2

Ref. WAIS-R Manual (1981)

Scales Scores Equivalents of Raw Scores—Ages 70-74

Verbal		Performance	
Scaled Score	Digit Span	Block Design	Digit Symbol
19	24-28	44-51	72-93
18	-	41	65-71
17	23	43	59-64
16	22	39-40	53-58
15	20-21	35-38	49-52
14	18-19	33	46-48
13	17	34	43-45
12	16	29-32	39-42
11	14-15	25-28	34-38
10	13	22-24	29-33
9	11-12	20-21	25-28
8	10	16-19	21-24
7	9	13-15	18-20
6	8	10-12	14-17
5	7	6-9	10-13
4	6	3-5	7-9
3	3-5	2	4-6
2	1-2	1	2-3
1	0	0	0-1

Ref. WAIS-R Manual (1981)

Scales Scores Equivalents of Raw Scores—Ages 55-64

Verbal			Performance	
Scaled Score	Digit Span		Block Design	Scaled Score
19	26-28		48-51	19
18	25		45-47	18
17	24		43-44	17
16	23		41-42	16
15	22		39-40	15
14	20-21		36-38	14
13	18-19		32-35	13
12	17		27-31	12
11	15-16		24-26	11
10	14		22-23	10
9	13		19-21	9
8	11-12		16-18	8
7	10		11-15	7
6	9		8-10	6
5	8		4-7	5
4	6-7		2-3	4
3	3-5		1	3
2	1-2		0	2
1	0		-	1

Ref. WAIS-R Manual (1981)

Relation of Scaled Scores to Deviations from the Mean and Percentile Ranks

Scaled Score on any Single Test	Number of SDs from the Mean	Percentile Rank	Scaled Score on any Single Test	Number of SDs from the Mean	Percentile Rank
19	+3	99.9	8	-1/3	37
18	+2 2/3	99.6	7	-2/3	25
17	+2 1/3	99	6	-1	16
16	+2	98	5	-1 1/3	9
15	+1 2/3	95	4	-1 2/3	5
14	+1 1/3	91	3	-2	2
13	+1	84	2	-2 1/3	1
12	+2/3	75	2	-2 2/3	0.4
11	+1/3	63	1	-3	0.1
10	0 (Mean)	50	0		

Ref. WAIS-R Manual (1981)

WAIS-R Subtest Scores for Persons 75 to 79 Years

Verbal		Performance	
Scaled Score	DSp	BD	DSy
19	24-28	41-51	70-93
18	23	38-40	63-69
17	22	35-37	58-62
16	10-21	33-34	51-57
15	18	31-32	48-50
14	16-17	28-20	44-47
13	15	24-27	41-43
12	14	21-23	38-40
11	13	19-20	34-37
10	12	14-18	29-33
9	11	12-13	25-28
8	10	9-11	20-24
7	9	6-8	18-19
6	8	3-5	12-17
5	7	1-2	8-11
4	5-6	0	6-7
3	2-4	-	3-5
2	1	-	1-2
1	0	-	0

DSp = Digit Span; BD = Block Design; DSy = Digit Symbol

Ref. Spreen & Strauss (1998)

APPENDIX K

Demographic Characteristics and Baseline Performance of the Test Sample

Test Statistics	Gender	HRT	Hand	Depressed
Mann-Whitney U	165.5	161	151.5	163.5
Wilcoxon W	355.5	351	341.5	334.5
Z	-0.2	-0.64	-1.1	-0.34
Asymp. Sig. (2-tailed)	0.84	0.52	0.27	0.74
Exact Sig. [2*(1-tailed Sig.)]	0.87	0.78	0.56	0.82
a	Not corrected for ties.			
b	Grouping Variable: training type:EF/EL			

Independent Samples *t*-tests		Levene's Test		*t*-test for Equality of Means						
		F	Sig.	*t*	df	Sig.(2-tailed)	Mean Diff.	Std. Error Diff.	95% C. I.	
	Equal variances:								Lower	Upper
AGE	assumed	0.02	0.9	1.95	35	0.06	2.81	1.44	-0.11	5.73
	not assumed			1.95	34.85	0.06	2.81	1.44	-0.11	5.73
EDUC	assumed	0.77	0.39	-0.89	35	0.38	-1.01	1.13	-3.31	1.29
	not assumed			-0.89	34.96	0.38	-1.01	1.13	-3.30	1.28
z score Intelligence	assumed	0.04	0.85	-0.79	35	0.44	-0.22	0.28	-0.78	0.34
	not assumed			-0.79	35	0.44	-0.22	0.28	-0.78	0.34
z score Memory	assumed	0.16	0.69	0.59	35	0.56	0.19	0.33	-0.47	0.85
	not assumed			0.59	34.36	0.56	0.19	0.33	-0.47	0.85
z score Attention	assumed	0.95	0.34	-0.43	35	0.67	-0.13	0.30	-0.74	0.48
	assumed			-0.43	33.33	0.67	-0.13	0.30	-0.74	0.48

Independent Samples *t*-tests:		Levene's Test		*t*-test for Equality of Means						
Accuracy Baseline 1		F	Sig.	*t*	df	Sig.(2-tailed)	Mean Diff.	Std. Error Diff.	95% C. I.	
	Equal variances:								Lower	Upper
baseline 1 z score L+R arrows	assumed	0.65	0.43	-0.38	35	0.71	-0.17	0.46	-1.12	0.77
	not assumed			-0.38	34.99	0.71	-0.17	0.46	-1.12	0.77
baseline 1 mean accuracy, L	assumed	2.95	0.10	0.27	35	0.79	0.15	0.58	-1.03	1.33
	not assumed			0.27	32.93	0.79	0.15	0.58	-1.02	1.33
baseline 1 mean accuracy, R	assumed	0.71	0.41	1.29	35	0.21	1.04	0.81	-0.60	2.68
	not assumed			1.30	31.127	0.20	1.04	0.80	-0.59	2.67

Independent Samples *t*-tests:		Levene's Test		*t*-test for Equality of Means						
RT Baseline 1		F	Sig.	*t*	df	Sig.(2-tailed)	Mean Diff.	Std. Error Diff.	95% C. I.	
	Equal variances:								Lower	Upper
baseline 1 mean RT, L	assumed	1.13	0.30	0.62	29.00	0.538	0.48	0.77	-1.09	2.04
	not assumed			0.62	25.44	0.543	0.48	0.77	-1.12	2.07
baseline 1 mean RT, R	assumed	0.73	0.40	-0.03	29.00	0.974	-0.02	0.69	-1.43	1.39
	not assumed			-0.03	28.12	0.974	-0.02	0.68	-1.42	1.38

APPENDIX L

Number of Training Trials to Reach Criterion

Group Statistics

	Training	N	Mean	S.D.	Std. Error Mean
Session 1	EF	18	2.89	0.96	0.23
	EL	19	2.74	0.99	0.23
Session 2	EF	18	2.28	1.13	0.27
	EL	19	2.11	1.24	0.29

Indepependent Samples Test

		Levene's Tes		t-test for Equality of Means						
		F	Sig.	*t*	df	Sig.	Mean Diff.	Std. Error Diff.	95% C. I. of the Diff.	
	Equal variance:					(2-tailed)			Lower	Upper
Session 1	assumed	0.58	0.45	0.47	35	0.64	0.15	0.32	-0.5	0.8
	not assumed			0.47	35	0.64	0.15	0.32	-0.5	0.8
Session 2	assumed	0.14	0.71	0.44	35	0.66	0.17	0.39	-0.62	0.97
	not assumed			0.44	34.9	0.66	0.17	0.39	-0.62	0.96

APPENDIX M

Number of Participants Who Met Criterion

Descriptive Statistics

	N	Mean	S.D.	Minimum	Maximum
post test 1	37	0.35	0.48	0	1
baseline 2	37	0.16	0.37	0	1
post test 2	37	0.35	0.48	0	1
training type:EF/EL	37	1.51	0.51	1	2

Participants Meeting Criterion

	post test1	baseline2	post test2
EF	5	2	6
EL	8	4	7
Total	13	6	13

Ranks for Met Criterion

	Training	N	Mean Rank	Sum of Ranks
post test1	EF	18	17.64	317.5
	EL	19	20.29	385.5
	Total	37		
baseline2	EF	18	18.06	325
	EL	19	19.89	378
	Total	37		
post test 2	EF	18	18.67	336
	EL	19	19.32	367
	Total	37		

Test Statistics for Meeting Criterion

	post test1	baseline2	post test2
Mann-Whitney *U*	146.5	154	165
Wilcoxon W	317.5	325	336
Z	-0.9	-0.81	-0.22
Asymp. Sig. (2-tailed)	0.37	0.42	0.83
Exact Sig. [2*(1-tailed Sig.)]	0.467	0.62	0.87
a	Not corrected for ties.		
b	Grouping Variable: training type:EF/EL		

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